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Raysin, Kent L.

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THESIS

A COMPARISON OF OBSERVED AND PREDICTED AMBIENT NOISE IN THE NORTHEAST PACIFIC, WINTER 1980

by

Kent L. Raysin

June 1984

Thesis Advisor: C.R. Dunlap

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using archived fields from Fleet Numerical Oceanography Center for the simultaneous time and location.

The difference between the predictions and measurements was calculated. A maximum mean error of 4.9 dB occurred at 200 Hz which appeared to be due to errors in the DANES Historical Temporal Shipping (HITS) data base. The model was insensitive to synoptic shipping, sound speed profiles and wind field inputs when the HITS data base was utilized.

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A Comparison of Observed and Predicted Ambient Noise in the Northeast Pacific, Winter 1980

by

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

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ABSTRACT

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LIST OF ABBREVIATIONS / ACRONYMS

AN	Ambient Noise
ASEPS	Automated Signal Excess Prediction System
ASNI	Ambient Sea Noise Indicator
ASRAPC	Acoustic Sonar Range Prediction C
ASTRAL	ASEPS Transmission Loss
ASTREX	Acoustic Storm Transfer & Response Experiment
AXBT	Air Expendable Bathythermograph
CNOC	Commander, Naval Oceanography Command
CNOISE	Ambient Sea Noise Model
COMTHIRDFLT	Commander, Third Fleet
CZ	Convergence Zone
DANES	Directional Ambient Noise Estimation System
dB	Decibel
EARG	Environmental Acoustic Research Group
EOTS	Expanded Ocean Thermal Structure
FANM	Fast Ambient Noise Model
FFT	Fast Fourier Transfer
FNOC	Fleet Numerical Oceanography Center
ft	Feet
GMT	Greenwich Mean Time
HITS	Historical Temporal Shipping
Hz	Hertz
kHz	Kilohertz
kt	Knot
kts	Knots
m	Meters
MANOVA	Multivariate Analysis of Variance
N	North latitude
NAVAIR	Naval Air Systems Command
NAVOCEANO	Naval Oceanographic Office
NDBC	NOAA Data Buoy Center

NEPAC	Northeast Pacific
NOAA	National Oceanic and Atmospheric Administration
NORDA	Naval Ocean Research and Development Activity
NPS	Naval Postgraduate School
NUSC	Naval Underwater Systems Center
ODSI	Ocean Data Systems, Incorporated
PE	Parabolic Equation (Ocean)
PE	Primitive Equation (Atmosphere)
RMS	Ross, Mahler, Solomon
RMS	Root Mean Square
SAI	Science Applications, Incorporated
SIAM	Simulated Ambient Noise Model
SLD	Sonic Layer Depth
SOFAR	Sound Fixing and Ranging
SST	Sea Surface Temperature
SSP	Sound Speed Profile
STD DEV	Standard Deviation
SYNBAPS	Synthetic Bathymetric Profiling System
TAPPS	Towed Array Performance Prediction System
TDS	Tactical Data System
TL	Transmission Loss
USI	Underwater Systems, Incorporated
VP	Aviation Patrol
W	West Longitude
WMO	World Meteorological Organization
Z	Zulu Time

I. INTRODUCTION

A. PURPOSE

The Directional Ambient Noise Estimation System (DANES) has been selected as the U.S. Navy's ambient noise prediction model for fleet use. It has been under operational evaluation at Fleet Numerical Oceanography Center (FNOC) in Monterey, Ca. for a number of years. This thesis provides an evaluation of DANES perfomance in the Northeast Pacific Ocean during November-December 1980.

The primary purpose of the study was to determine any prediction errors and to investigate the source of such errors. This was done by a comparison of the predictions with in situ noise measurements. As a part of this effort, the effects of local versus distant wind generated noise were also investigated.

B. APPROACH

First, the dominant mechanisms for the generation of ambient noise were reviewed. Recent research has generated a number of competing mechanisms for noise generation, especially for wind related noise. A summary of these mechanisms are provided in chapter two. Next, the models for ambient noise prediction were considered. General computer noise modeling techniques were summarized. The DANES model was reviewed in depth. This review and previous evaluations of the DANES model are also presented as background material in chapter two.

DANES ambient noise hindcasts were statistically compared to their corresponding measured ambient noise values in the ocean. The ambient noise measurements were obtained by the Environmental Acoustic Research Group (EARG) of the Naval Postgraduate School (NPS) in 1980. Archived data acquired from FNOC were used as inputs to the DANES model. The hindcasts were made at NPS for the appropriate times and locations for the ambient noise data that were previously acquired. The treatment of these data is found in chapter three.

The results from these comparisons of modeled and observed noise data are provided in chapter four. Discussion of the results and conclusions are found in chapters five and six, respectively.

II. BACKGROUND

A. GENERAL - WENZ CURVES

Measurements of background noise in the ocean have been made over a broad range of frequencies, from 1 Hz up to about 100 kHz (Urick, 1983). The ambient noise has different characteristics at different frequencies and must therefore originate from a variety of sources. The three prevailing sources according to Wenz (1962) were turbulent-pressure fluctuations from ocean currents (below 100 Hz), oceanic shipping traffic (10 to 1000 Hz) and wind generated bubbles and spray (above 100 Hz), Figure 2.1 . Modified Wenz curves (Figure 2.2) have since become an integral part of the U.S. Navy ambient noise prediction system. These modified curves continue to be used operationally for on-scene predictions.

B. SHIPPING RELATED AMBIENT NOISE

Shipping related ambient noise is dominated by propeller cavitation (Ross, 1976). Cavitation generated noise is proportional to the number of blades, propeller diameter, and tip speed with the latter being the dominant factor. These factors can be related to ship size and speed for noise spectrum estimations. The ocean traffic curves (Figure 2.1) represent the noise resulting from the combined effect of all shipping (Wenz, 1962). This combined effect is dependent on transmission loss, the number of ships and the distribution of the ships. Ambient noise studies have shown shipping related noise to be highly variable, both geographically and seasonally.

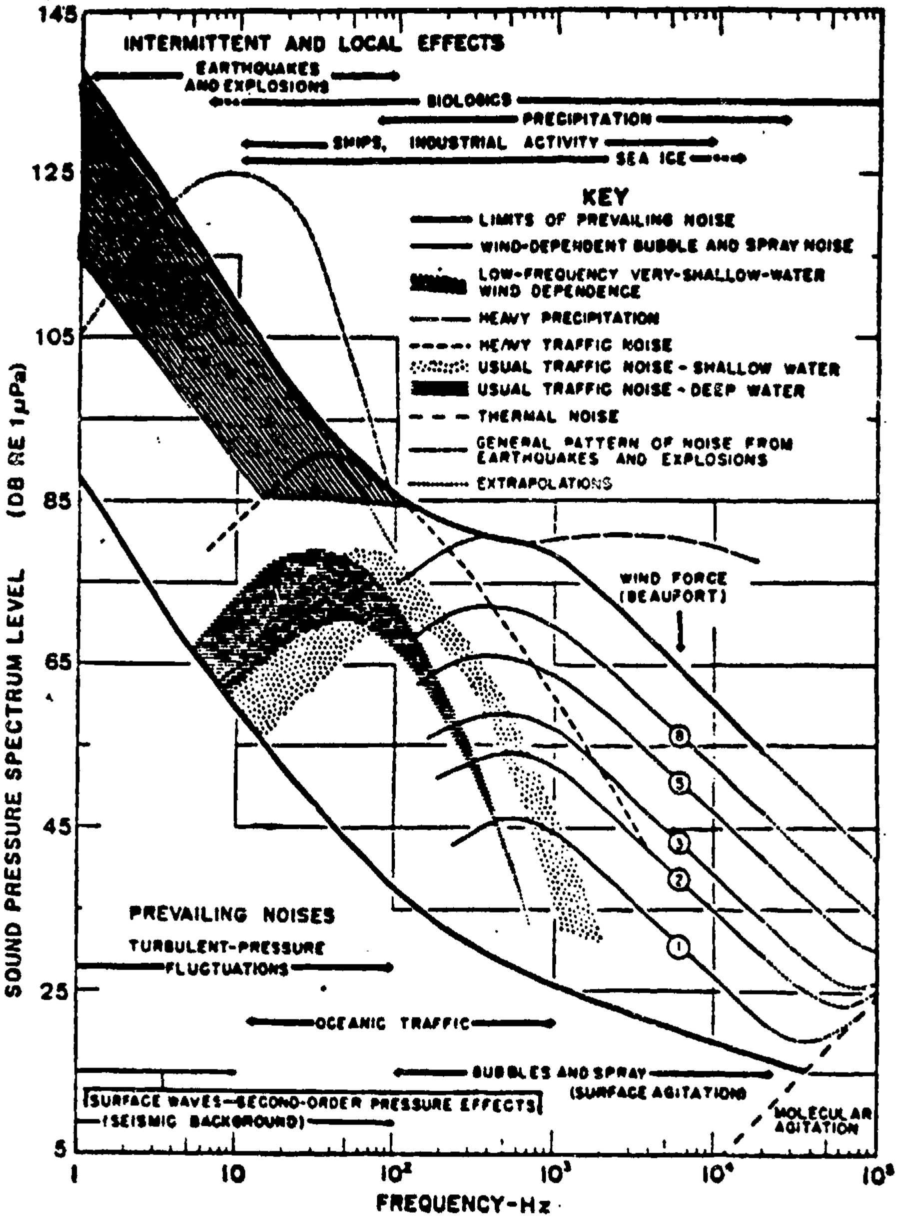

Figure 2.1 Ambient Noise Spectra (From Wenz, 1962)

C. WIND RELATED AMBIENT NOISE

Since Wenz (1962) first summarized the sources of ambient noise in the ocean, numerous theories have been presented on the wind related mechanisms for ambient noise generation. In the following sections, a more complete

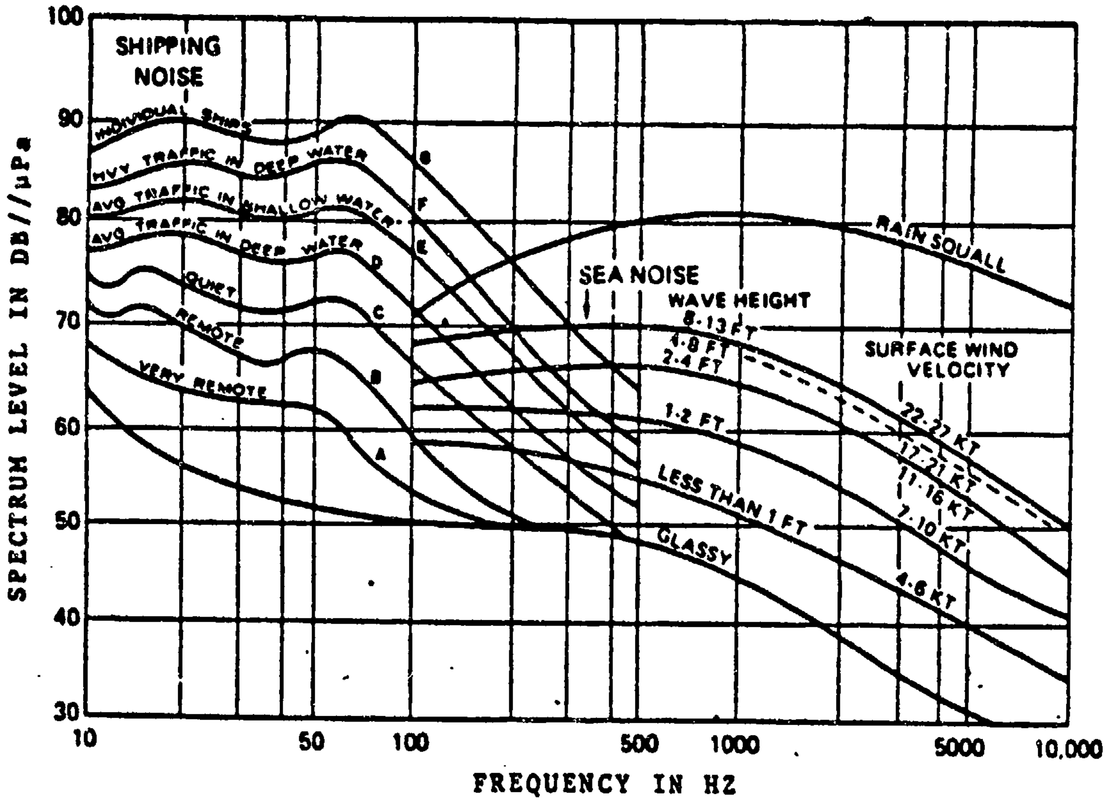

Figure 2.2 Modified Wenz Curves (From CNOC, 1981)

description of the wind related mechanisms will be discussed as they are currently understood.

1. <u>Flow Noise (below 100 Hz)</u>

Wagstaff (1983) describes flow noise as a form of self noise caused by the motion of the hydrophone relative to the water. This noise was referred to as turbulent-pressure fluctuations (see Figure 2.1) by Wenz (1962). For a bottom mounted hydrophone, flow noise would be due to ocean currents; whereas, for a towed array, the tow speed would be the primary factor. A floating sonobuoy, however, would be affected by the motion of the wind generated waves and the wind drift of the sonobuoy. The effects of flow noise can be reduced by either encasing the hydrophone, which may separate it from the medium, or by decoupling the hydrophone from the motion of the rest of the sonobuoy.

2. Surface Waves (1 to 10 Hz)

The fluctuation in the sea surface elevation due to the wind stress produces pressure fluctuations which appear as noise to a pressure sensitive acoustic system. The amplitude of these fluctuations decrease exponentially with depth, penetrating into the ocean to a distance of the order of one wavelength (Li, 1981). For frequencies above 1 Hz, this is less than 1.6m and, as such, can be neglected. However, another more significant surface wave ambient noise generating mechanism has been suggested by Longuet-Higgins (1950).

3. Wave-Wave Interactions (1 to 1000 Hz)

Longuet-Higgins (1950) showed that the exponential decay of a single progressive surface wave does not occur when two waves collide from opposite directions. Such interactions may form a standing wave which produces pressure fluctuations that are constant with depth at a frequency twice that of the generating surface waves. These waves can be experienced in the open ocean where the winds associated with an atmospheric cyclonic depression produce opposing wave patterns. Additionally, in areas of variable winds, the required wave patterns may be obtained at high capillary/gravity-wave frequencies. Wenz (1962) referred to these wave-wave interactions as surface wave second-order pressure effects in the region of 1 to 1000 Hz (see Figure 2.1).

This theory was further examined by Hughes (1976) utilizing a model of interacting oppositely traveling surface waves. Hughes calculated spectral noise levels for 1 to 3000 Hz. However, in comparison with the measurements of Perrone (1969), there was agreement only for frequencies of less than 10 Hz.

4. Wave-Ocean Turbulence Interaction (above 10 Hz)

The previous theory provided a possible explanation for the generation of ambient noise by the interaction of surface waves with each other. Another possible source of noise is the interaction of surface waves with oceanic turbulence (Goncharov, 1970). Goncharov showed that the noise generated by surface waves interacting with ocean turbulence exceeded the levels for wave-wave interactions at frequencies greater than 10 Hz. Estimated source spectrum levels generated by Goncharov were in reasonable agreement with experimental data presented by Furduyev (1963). However, this theory has not been developed further.

5. Wind Turbulence (5 to 50 Hz)

Isakovich and Kur'yanov (1970) showed that the spectral density of the noise field was related to the spectral density of the atmospheric turbulent pressure fluctuations near the ocean surface. However, no direct measurements of the atmospheric turbulent pressure fluctuations for an ocean environment were made. Isakovich and Kur'yanov also derived a relationship of the atmospheric pressure fluctuations to the spectral density of the sea state. These two relationships provided a means to determine the noise spectrum as a function of the sea state, which is wind dependent.

Wilson (1979) further developed this theory by introducing the Mitsuyasu and Honda (1974) wave spectrum which provided data for higher wave frequencies (above 30 Hz). Additionally, Wilson made different approximations in integration and algebra that significantly affected the final results. His results indicated excellent agreement with measurements obtained in the Northeastern Pacific Ocean by Morris (1978) for frequencies between 5 and 50 Hz.

6. Spray (50 to 1000 Hz)

Noise generated by the spray of water droplets on the surface of the ocean was investigated by Franz (1959). Since then, this source has been considered a contributing factor in ambient noise generation above 100 Hz (Wenz, 1962; and Urick, 1983). The generation of the ocean spray as a function of wind speed is not well known. Possible explanations have been the shearing of water from the wave crest, bubbles bursting on the ocean surface or suction of water droplets from the crests of capillary waves (Wilson, 1980).

A white cap index has been developed by Ross and Cardone (1974). This index relates wind speed to the percentage of ocean surface covered by spray, streaks and white caps. Wilson (1980) utilized the white cap index, measurements by Morris (1978), and the impact results of Franz to model ambient noise empirically between 50 and 1000 Hz.

7. Bubbles (above 100 Hz)

Wenz (1962) indicated that oscillating bubbles, which occur particularly near the ocean surface due to the effects of the wind, are effective sound sources. Air bubble oscillation is important at the natural frequency of oscillation for the zero mode. This frequency is inversely proportional to bubble size. Since there is a practical limit to how large the bubble can become, then there is a lower frequency limit to the bubble generated noise spectrum. Wilson (1980) indicates this lower limit is approximately 1000 Hz based on a maximum bubble size of .3 cm.

Bubbles rise toward the surface and expand to maximum size as a result of decreasing hydrostatic pressure. Bubbles either will reach the surface and burst, or collapse upon reaching a critical size prior to arrival at the surface. In either case, the bursting bubbles generate cavitation noise. This source of noise has been investigated by a number of individuals. Wenz (1962) presented a summary of previous works, concluding that "the spectrum shape of cavitation noise was similar to that of air-bubble noise, which resembles the spectrum shape of wind dependent ambient noise." Later work by Furduyev (1966) theoretically showed that cavitation produced the broad peak in the wind noise spectrum between 100 and 1000 Hz.

8. Distant Storms

The majority of the theories presented treat wind generated noise as being a local effect due to the dipole nature of the source. As a dipole source, the majority of the energy in the sound waves is directed vertically downward. The resulting steep projection angles preclude long range propagation of the energy. Measurements made by Wilson (1983) in the Northeast Pacific, however, indicate that distant storms can influence the noise spectrum in regions of low shipping. Noise levels obtained at 165 Hz were well correlated to the presence of a distant storm and were considerably higher than would be experienced for the local wind conditions.

Wilson (1983) proposed a theory by which the noise generated by a storm could propagate to a distant receiver. The noise level from the storm was modeled utilizing a rocking dipole factor. The rocking dipole factor accounts for the irregular ocean surface and nonvertical impact of spray during the storm. This factor is proposed for the frequency range of 50 to 1000 Hz where the impact spray is assumed to be the dominant noise source. Due to absorption, only the lower frequency energy would be expected to propagate to any significant distance. Wilson's model predictions agreed well with the measurements he made in the Northeast Pacific.

Another possible explanation for the apparent effects of distant storms could be given from work presented by Li (1981). Li derived, from the continuity and momentum equations, a general differential equation for the generation of noise. For wind induced noise Li stated that there were two dominant terms. The first term involves turbulent stresses and compressive stresses acting on the boundary layer. These stresses are of a dipole nature. The second term is due to the motion of the boundary layer and acts as a monopole source. This monopole source therefore would produce noise that travels along horizontal rays that could propagate for long distances.

D. NOISE MODELING

Wind generated ambient noise is a complex phenomenon. When coupled with shipping noise and other noise generating mechanisms such as ice, rain or biologics, the ambient noise spectrum becomes extremely difficult to predict. Numerous prediction models have been developed to estimate average noise levels. These have ranged from simple empirical models using the modified Wenz curves to more complex computer models. Most models concentrate on two primary sources of noise: wind generated noise above 200 Hz, and distant shipping noise below 500 Hz (Anderson, 1982).

The various computer models may be categorized by the method utilized to derive the noise contribution from distant shipping (Cavanaugh, 1977). These methods are usually one of three basic designs: empirical models, field models, and point models. From Table I , the method utilized to represent shipping is not the only difference between the models. Other key distinguishing features are the way the transmission loss is modeled and the method by which the noise level predictions are computed and presented.

TABLE I

Ambient Noise Model Characteristics (After Anderson, 1982)

MODEL	SHIPPING	WIND	TRANS-MISSION LOSS	SOUND SPEED PROFILE	PREDIC-TION METHOD	OUTPUT PARA-METER	REFERENCE
CNOISE	Field	None	External	TL model dependent	Determ-inistic	Mean Level	Cornyn, 1980
DANES	Field + Synoptic Point	Distant and/or Local	ASTRAL	Multiple	Determ-inistic	Mean Level	Osborne, 1979
FANM	Field	Local	Ray Trace	Single	Determ-inistic	Mean Level	Cavanaugh, 1974
SIAM	Point	None	External	TL model dependent	Simula-tion	Mean, Median, Distri-bution	SAI, 1977
TAPES	Empir-ical	Local	None	Single	Empir-ical	Mean Level	Garon and Spofford, 1979
USI	Field	None	External	TL model dependent	Analy-tical	Mean, Median, Distri-bution	Jennette et.al. , 1978

Empirical models utilize archived data and extrapolation algorithms to determine the noise levels generated due to shipping. Models of this type, such as the TAPPS model shown in Table I, do not compute transmission loss. A sound speed profile input to TAPPS is utilized, however, to determine limiting ray angles at the surface and bottom, and critical angles. These ray angles are used to determine the depth dependence of the noise due to surface-image interference.

Field type models represent the shipping in a geographical distribution which is modeled as a continuum of point sources. Models of this type shown in Table I are typically deterministic; that is, they propagate the energy from the various sources back to the receiver where the sum of the sources then is calculated. The USI model is the only exception to this procedure. In this model the noise level is determined analytically by calculating the probability of each possible received noise level which has been identified by the transmission loss model.

The only point model in Table I is the SIAM model. This model simulates distant ships as point sources and propagates the energy from each source back to the receiver. The noise level in the SIAM model is calculated by simulating ship motion for randomly distributed ships over a given time period. Like the USI model, this approach produces not only a mean noise level but also the expected distribution of the noise.

E. DANES MODEL

The Directional Ambient Noise Estimation System (DANES) is the primary model used in the present study. It is one of more than twenty-two ambient noise computer models developed in the last decade (Anderson, 1982). The model is capable of providing horizontal directional noise estimations for user specified arbitrary locations and receiver parameters. Currently, DANES models four sources of ambient noise. The sources are geographically distributed historical ships, discrete ships, local wind and far-field winds. As a component part of a more general acoustic computer model known as ASEPS (Automated Signal Excess Prediction System), DANES makes use of the ASEPS database, geometry, propagation and noise accumulation technology. The following discription of the DANES model is taken primarily from the ODSI Defense Systems, Inc. publications prepared for NORDA.

1. Transmission Loss

DANES uses the ASEPS Transmission Loss (ASTRAL) model developed by Science Applications, Inc. (SAI) (Spofford, 1979). ASTRAL is a fast, range dependent model which produces range smoothed transmission loss predictions, averaged over 30 to 40 nm increments. A comparison of ASTRAL and the Parabolic Equation (PE) model outputs appears in Figure 2.3 . The only difference between the model inputs is that the PE prediction is computed for a fully absorbing bottom. The range averaging of ASTRAL precludes convergence zone (CZ) effects which are present in the PE curve, Figure 2.3 .

The ASTRAL calculations are performed in two parts; a near field and a far field. In the near field, rays are computed for a given sound speed profile (SSP) out to the first environmental change, which is specified as 150 nm for DANES. The SSP utilized is assumed to be piecewise linear so that the rays computed are arcs of circles. The bathymetry in the near field may be modeled either to vary linearly with range or as a step function of locally flat segments. At the first environmental change, each computed

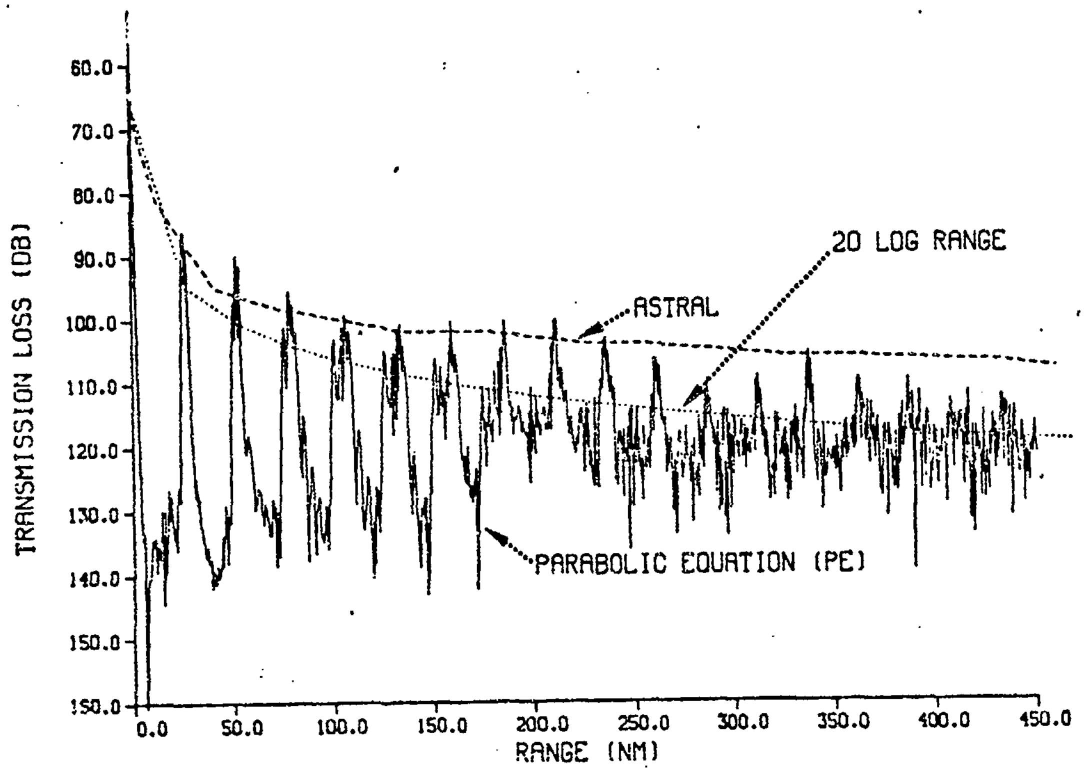

Figure 2.3 Comparison between ASTRAL and PE TL Models

ray is associated with a "mode" by its turning point sound speed (phase velocity). In the far field region the step function bathymetry is utilized along with piecewise linear SSP's. The "modes" generated at the first environmental change are propagated, assuming adiabatic invariance for each mode. At each ensuing environmental change along the propagation path, the phase integral is maintained by choosing a new sound speed for the turning point. Losses are computed for surface and bottom interaction and volume attenuation.

For the DANES model, ASTRAL provides an angular representation of the receiver acoustic field of view. The receiver is positioned at the center with each propagation sector extending outward along a great circle route at specified radials. Transmission loss is computed along each path until the loss exceeds 150 dB or the maximum range of 6000 nm has been obtained. The SSP's utilized for ray computations are extracted from climatological watermass files. In the near field, the user may specify a synoptic SSP. Bathymetric data are obtained from the NORDA Synthetic Bathymetric Profiling System (SYNBAPS) data base (Van Wyckhouse, 1973).

2. Shipping Noise

The primary ambient noise source utilized by DANES is the geographically distributed shipping densities. This noise source is extracted from the Historical Temporal Shipping (HITS) data base compiled by Solomon et al. (1978). The data base is tabulated by 1-degree squares and ship type. Noise from each 1-degree square along the transmission path is propagated towards the receiver for noise accumulation. The shipping spectrum utilized varies with ocean basin as given in Table II. The source depth is set at 6.1m (20 ft).

TABLE II

DANES Shipping Level Spectra (dB re uPa)

	10Hz	50Hz	300Hz
Atlantic Ocean	180.0	173.5	149.0
Indian Ocean	180.5	174.0	149.5
Mediterranean Ocean	180.5	174.0	149.5
Pacific Ocean	177.5	171.0	146.5

A discrete file of synoptic shipping may be inserted in addition to the HITS data. This file is obtained from the World Meteorological Organization (WMO) reporting system. Each WMO ship that falls within ASTRAL's propagation range is dead reckoned (based on position, course, speed and time of report) to a position corresponding to the time of prediction. The ship noise level contribution is then computed according to the transmission loss profile along the radial for which the WMO ship is found. The spectra and source depth utilized are the same as that for HITS.

3. Wind Noise

Wind generated ambient noise is computed utilizing the source level spectra shown in Figure 2.4 . These curves depend primarily on Wilson (1979 and 1980) where, the spectra reflect the effects of wind turbulence below 50 Hz; 50 to 1000 Hz, the effects of spray; and above 1000 Hz, the effects of oscillating bubbles. The one- and five-knot wind curves were added from data provided by Cavanaugh (1982) The local wind speed can be obtained by DANES either from user input or from synoptic/forecasted wind files. Far field wind effects may also be included when wind files are utilized. The far field wind noise is propagated, utilizing ASTRAL, from a 6.1m (20 ft) source depth back to the receiver in a manner similar to that used for shipping noise.

F. PREVIOUS DANES EVALUATIONS

1. Theoretical Evaluation

According to Wagstaff (1983), there are two primary flaws in the way DANES models ambient noise. The first flaw is the "tuning" of the shipping source level spectrum to a specific ocean basin, and the second is the use of the propagation loss model ASTRAL.

Tuning a model by adjusting the shipping spectra is a reasonable technique for obtaining an average world wide spectrum. However, according to Wagstaff, this tuning should produce one spectrum that is independent of ocean basin. This spectrum should reflect the average for all

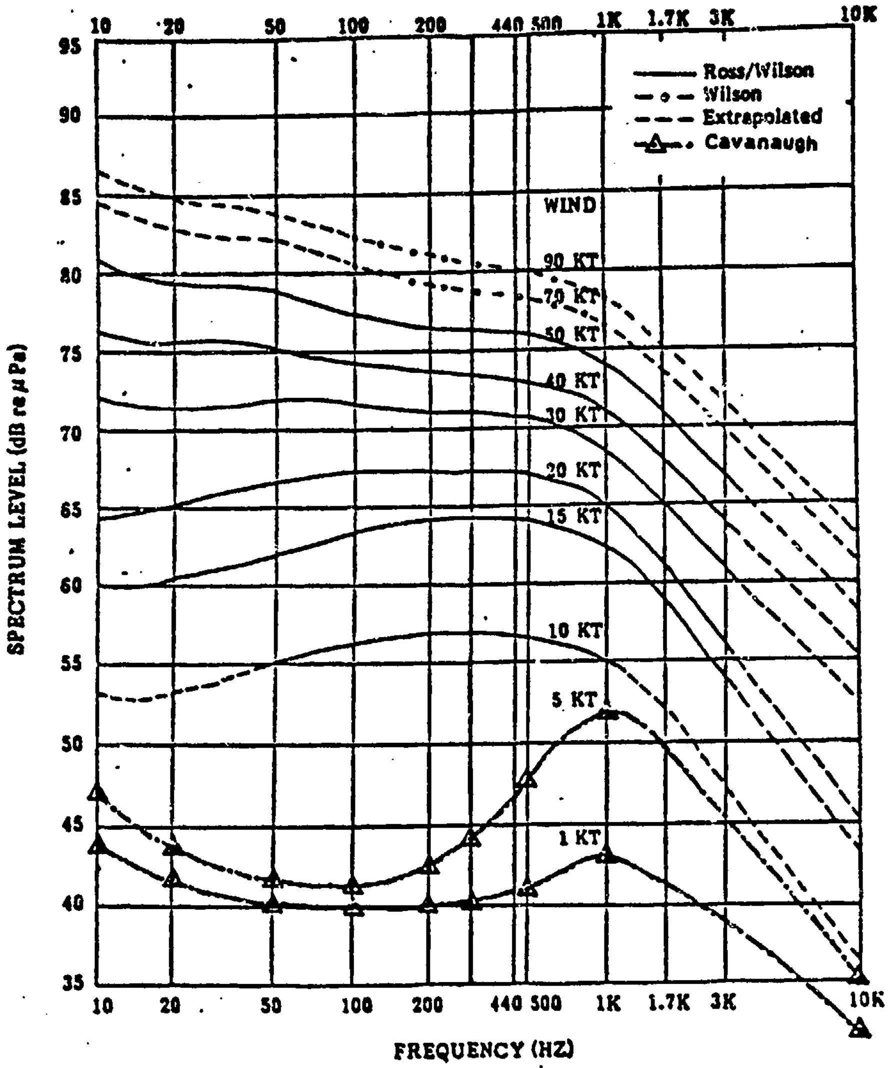

Figure 2.4 DANES Wind Level Spectra (From ODSI, 1981)

measurements obtained at different depths, locations, seasons and oceans.

Wagstaff states that the reason DANES requires the shipping spectra to be tuned by ocean basin is due to the transmission loss model utilized. Since ASTRAL is a range averaging propagation model, it does not predict enhancement in propagation loss due to the down slope conversion mechanism. Without this mechanism, the energy contained in the SOFAR channel will not be modeled properly (Wagstaff, 1981).

Hence, in ocean basins where the SOFAR channel is a dominant feature, the noise spectra need to be adjusted to account for this missing transmission path.

2. Model Comparisons

a. NAVOCEANO Study

Anderson (1982) evaluated the six ambient noise prediction models presented in Table I in an attempt to identify the best model for U.S. Navy use. His results indicated that each model performance was dependent on the ocean basin, frequency and the depth of interest. No one ambient noise model appeared to be universally superior to the other models.

The TAPPS model was consistently poor in every area except one. At 50 Hz for a hydrophone depth of 18m (60 ft), the TAPPS model produced predictions 2 to 8 dB better than any other model. This result occurred because, at the time of evaluation by Anderson, the transmission loss model in TAPPS was the only model that considered surface decoupling.

In the Pacific, DANES generally provided better estimates of the noise level than the other models evaluated. The mean error for DANES was approximately equivalant to that from other models, or 2 to 8 dB better, for all frequencies and depths, except as previously stated for 50 Hz. In general, DANES overestimated the noise levels in the shipping frequencies of 50 and 150 Hz. The lowest absolute errors occurred at 300 Hz for both the 18m (60 ft) and 91m (300 ft) hydrophone depths.

The results for the Atlantic were considerably different. DANES performance was relatively poorer than most of the other models. At 50 Hz, the mean errors were comparable to the other models. However, the error was 1 to

6 dB greater than the FANM model, which performed the best at 150 Hz; and 4 to 6 dB more than CNOISE at 300 Hz. In the shipping frequencies, DANES tended to underestimate the noise level in the Atlantic (instead of overestimating it as occurred in the Pacific).

Anderson concluded that DANES was an acceptable model for U.S. Navy use. The capability of DANES to utilize synoptic shipping data coupled with historical shipping was considered a desirable feature. He recommended that DANES incorporate a method of calculating the expected noise distribution similar to the method used in the USI model.

The DANES model evaluated by Anderson was an early version. The shipping data base utilized by DANES at that time was the RMS (Ross, Mahler, Solomon, 1974) shipping density data base which has since been replaced by HITS (Solomon et al., 1978). Additionally, the HITS shipping noise spectrum has been adjusted according to ocean basin. Other changes which could affect the results obtained include the addition of surface decoupling effects to ASTRAL, and the change from the Wittenborn (1977) wind spectrum to the Ross-Wilson spectrum.

b. COMTHIRDFLT Study, First Report

COMTHIRDFLT (1982) presented a comparative analysis of three ambient noise prediction techniques utilized by the aviation patrol (VP) community. The three critera considered for a valid prediction were as follows:

1) DANES:

The DANES prediction was required to be for a location within three degrees latitude and longitude of the measurement. The prediction time had to be within three hours and generated within 24 hours of the observation. The noise prediction also had to be for a depth within 50 feet of the VP measurement depth.

2) Modified Wenz curve:
This prediction was required to utilize a selected shipping curve for a given area and the forecasted wind speed provided by the DANES message.

3) Last Flight:
This method of prediction was required to utilize the last ambient noise reading obtained by the previous VP flight that was within three degrees latitude and longitude and 36 hours of the comparison measurement.

After invoking the above criteria, 149 comparisons were generated. Table III provides a comparative

TABLE III

Percent Correct Forecasts (After COMTHIRDFLT, 1982)

Within 2 dB

Frequency	DANES	Wenz	Last Flight
50 Hz	47	38	34
100 Hz	24	32	42
200 Hz	30	42	31
440 HZ	38	42	29

Within 4 dB

Frequency	DANES	Wenz	Last Flight
50 Hz	66	62	60
100 Hz	51	60	63
200 Hz	40	61	55
440 HZ	59	63	54

summary of the predictions and the observations. The numbers provided are the percentage of predictions which were within 2 and 4 dB of the measured values. DANES appears to provide the best prediction at 50 Hz but is surpassed by the Wenz curve estimations at higher frequencies. Not indicated by the data shown, but addressed in the original report, was that the DANES prediction errors were highly dependent on location at 100 and 200 Hz.

c. EARG Study

At the Naval Postgraduate School (NPS), the Environmental Acoustic Research Group (EARG) has investigated ambient noise in the ocean on a continuing basis since 1979. Geographical areas of interest have included the Northeast Pacific, the Bering Sea and the Norwegian Sea. One such study was conducted by Donovan (1982) in which comparisons were made between three ambient noise model predictions and in situ noise observations in the Northeast Pacific. His work was of a cursory nature with the ambient noise predictions being made for a general location near the measurement. Donovan results indicated that DANES appeared to overestimate the noise spectrum; however, Donovan reached no conclusions concerning which model was the most accurate. Other studies by the EARG have found that DANES underestimates the noise spectrum in the Bering Sea, mainly due to the HIIS data base errors (Dunlap, 1984).

3. Statistical Evaluations

a. NUSC New London Study

A study to determine the accuracy of DANES ambient noise estimations for surveillance and mobile sonar systems was performed by NUSC, New London (Malay 1982). The analysis consisted of the comparison of DANES predictions obtained from FNOC with observed noise levels recorded at the NUSC Tudor Hill Laboratory in Bermuda. In the study, hourly measurements of the ambient noise at 25, 50, and 150

Hz were obtained along with the wind speed at the laboratory. Daily DANES ambient noise estimations for 0000Z and plus 24 hours were received from FNOC for the comparison. Malay's results indicated that both forecasts were usefully accurate. However, the accuracy was limited because of short term variations in the wind speed, the number of local fishing boats, and single ship transits.

b. COMTHIRDFLT Study, Second Report

A statistical comparison between DANES predictions and VP measured ambient noise levels was performed by COMTHIRDFLT (1982). Statistics were generated for predictions that were within 24 hours and 100 nm of an aircraft in situ measurement. Differences in predicted and measured noise levels were computed as a function of the originating flight station (Barbers Point or Moffett Field), sonobuoy depth (60, 400, 1000 ft), and frequency (50, 100, 200, 440 Hz). Additionally, a Multivariate Analysis of Variance (MANOVA) tested the significance of depth or originating flight station on DANES performance.

Statistically DANES has a tendency to overestimate the ambient noise level by approximately 1 to 3 dB. The MANOVA statistics indicated that the sonobuoy depth is a statistically significant factor in the prediction error. A dependence on flight stations was noted, but could not be considered significant by the set standards. The standard deviation of the errors varied from 5 to 8 dB, depending on the flight station, sonobuoy depth and frequency. The lowest average errors and standard deviations occurred at the middle depths, and at the frequencies of 100, 200, and 440 Hz, indicating these to be the conditions for the most accurate predictions.

III. TREATMENT OF THE DATA

A. MEASUREMENTS

Sonobuoy ambient noise (AN) data were acquired during the Acoustic Storm Transfer and Response Experiment (ASTREX) of November and December 1980, cf. Holt (1981) and Donovan (1982). Holt utilized the "average" observed noise values as a subset of his study of the ambient noise characteristics of the Northeast Pacific (NEPAC). These averages were computed by VP aircrews from individual observations made on the P-3 aircraft Ambient Sea Noise Indicator (ASNI). Donovan analyzed analog recordings from the identical VP flights to construct observed ambient noise spectra. The observed spectra were compared to three predicted spectra derived from ambient noise prediction models: Wenz curve estimations; Acoustic Sonar Range Prediction C (ASRAPC) predictions; and DANES predictions.

The individual measurements recorded by VP flight crews and which generated the averages utilized by Holt, were used in this study. The reason these individual ambient noise meter readings were used was two-fold. First, it increased the data set from 44 observations in Holt's study and 12 observations in Donovan's study to 158 observations. Second, it eliminated the interpretation of an average noise level which differed between individual flight crews.

1. Observational Accuracy

The measurements during ASTREX could possess errors associated with the uncalibrated sonobuoys. A total of 46 sonobuoys were utilized to obtain 158 measurements. No one sonobuoy acquired more than five of the measurements utilized. This number is not considered to be large enough to bias the results; therefore, the sonobuoy error can be considered random. With a large enough sample size, random errors would be expected to produce a mean error of zero with a given standard deviation. Manufacturer specifications indicate this standard deviation to be variable with frequency. Sonobuoy sensitivity is given as 2 dB at 100 Hz (NAVAIR 28-SSQ-500-1).

Another possible error could be introduced by the aircraft systems. Because a different aircraft obtained the measurements on each day of the exercise, random system errors also exist from one day to the next. The measurements acquired on a particular date, however, contain a bias associated with the aircraft utilized. This bias could be reflected in the prediction error. When the data were arranged according to the day on which the observations were obtained, the results indicated that the first day of the experiment (15 November 1980) probably provided erroneous data. This will be discussed further in chapter four.

2. Nearby Shipping Effects

The VP flight crews annotated the ambient noise records when nearby shipping traffic was known to be present. To eliminate the effects of nearby shipping on the noise measurement, all measurements with a 50 Hz ambient noise meter reading above 89 dB were removed from the data set. This level was selected because it fell two standard deviations above Holt's (1981) average level, and, in practice, it excluded all measurements which had reported nearby shipping.

B. MODEL PREDICTIONS

The DANES model was run with various combinations of input parameters including frequency, receiver depth, geographic location, time, shipping, wind, and sound speed profile (SSP).

The frequency range of interest extended from 10 to 2000 Hz, concentrating on five of the six VP ASNI frequencies: 50, 100, 200, 440, and 1000 Hz. The depth and location of the receiver in the model were identical to that of each measurement. Since the 158 measurements had been acquired at various times, an exact match for time was not made to reduce computer processing requirements. One DANES estimation was produced to represent all measurements at a particular location within a one hour time frame. This procedure is considered valid since DANES is an "average" estimation of the noise level.

The shipping input to each model run consisted of one of four possibilities: the Pacific HITS data base; the Mediterranean HITS data base; the Pacific HITS data base plus the 0000 GMT FNOC WMO file; or the Mediterranean HITS data base plus the 0000 GMT FNOC WMO file. The Mediterranean data base was utilized to eliminate the HITS contribution and isolate either the wind or WMO noise source. The DANES model presently installed at NPS requires a HITS input to operate successfully. By using the Mediterranean HITS data base, the HITS shipping contribution was determined to be out of range for DANES computations and consequently ignored. The WMO ships were modified as a result of this procedure. Since the DANES shipping spectrum is adjusted according to the ocean basin, the spectrum was adjusted from that for the Pacific data base when the Mediterranean data base was specified.

Three possible wind inputs to the DANES model were utilized: (1) no wind, (2) field wind, and (3) local wind. The "no wind" input was selected to isolate the shipping contribution of the noise prediction. The wind field was derived from an atmospheric Primitive Equation (PE) model derived wind field, and it was extracted from FNOC's data base. This data base provided the capability to investigate the effects of both local and distant storm generated noise. The "local wind" input was not readily available. The archived wind fields were computer coded for compatability with DANES. The local wind speed utilized in calculating the noise estimation from these fields is not provided in the DANES output. Therefore, an indirect method of determining the atmospheric model generated local wind speed had to be utilized.

Assuming the high frequency noise levels are due to local effects only, the noise level estimates from the DANES wind field estimations at 1000 Hz were utilized. The wind speed associated with the 1000 Hz noise level value of the Ross-Wilson wind spectra was assumed to be the local wind. This assumption was supported by the fact that the ambient noise results above 400 Hz indicated little dependence on distant winds.

C. DATA ANALYSIS

1. General Approach

To investigate DANES accuracy, a statistical approach similar to that of COMTHIRDFLT (1982) was utilized. DANES predicted error was defined as the DANES predicted value minus the VP measured AN value. A mean error, root mean square (RMS) error, median error, and standard deviation of the errors were computed. The RMS error can be shown to be equal to the square root of the sum of the mean error squared plus the variation of the error (Jacobs, 1984). Conclusions were formulated on the differences in the statistics generated for each variable (i.e. frequency, depth, location, etc.)

2. Operational Parameters

Since the present study utilized hindcasts for the ambient noise, the ASTREX sonobuoy drop criteria dictated the frequency, depth, location and time of the DANES predictions. Separate statistics for each VP ASNI frequency were computed to evaluate DANES error as a function of frequency. To investigate the depth dependence of DANES prediction accuracy, the measurements and predictions were divided into three tactical depth categories: 60 ft, 300 or 400 ft, and 800 or 1000 ft. A location dependence was investigated for four latitude regions: 40.0 to 42.5N, 42.5 to 45.0N, 45.0 to 47.5N and 47.5 to 50.0N.

3. Noise Sources

DANES prediction errors associated with shipping noise contributions were investigated by isolating each shipping input. Comparisons were made between either HITS shipping predicted noise levels and measurements; or WMO shipping predicted noise levels and measurements. DANES is designed to operate with HITS as the only shipping source. However, to make WMO only predictions, the Mediterranean HITS data base had to be utilized as previously discussed.

To obtain a better understanding of the errors associated with DANES wind dependent noise estimates, an investigation was made of the error as related to the atmospheric PE model wind speed input to DANES. Since the input wind is itself a forecast with an unknown error, a portion of the DANES error could be related to this "input error". To evaluate this error the data were arranged according to forecasted local wind speeds and the ambient noise error statistics were generated by 5 kt blocks from 10 to 30 kts of forecasted wind speed.

4. Ocean Medium

To determine the importance of the SSP on estimated ambient noise levels, DANES model was run for a single measurement location utilizing three different SSPs. The first profile was the climatological SSP contained in the DANES data base. A synoptic SSP archived in the FNOC files was extracted as the second profile. This SSP had been computed utilizing climatological salinity data and a temperature profile from the Expanded Ocean Thermal Structure (EOTS) program. EOTS blends synoptic temperature profiles with climatological profiles. The third profile was also synoptic, but instead of using the FNOC EOTS temperature profile, AXBT data were used which had been aquired by the VP flight crews. The salinity values used were those reported by Toole et al. (1982). SSPs were computed utilizing Coppen's (1981) sound speed equation. The importance of using the VP AXBT directly was indicated by the existence of a warm core eddy which produced a warmer and deeper mixed layer. As a result, faster sound speeds, a deeper sonic layer, and a steeper gradient existed (Figure 3.1). As expected, the climatological and the FNOC analysis do not reflect accurately mesoscale eddy features such as that indicated by the VP AXBT. A cursory investigation was made of the acoustic effect of this eddy on the DANES error.

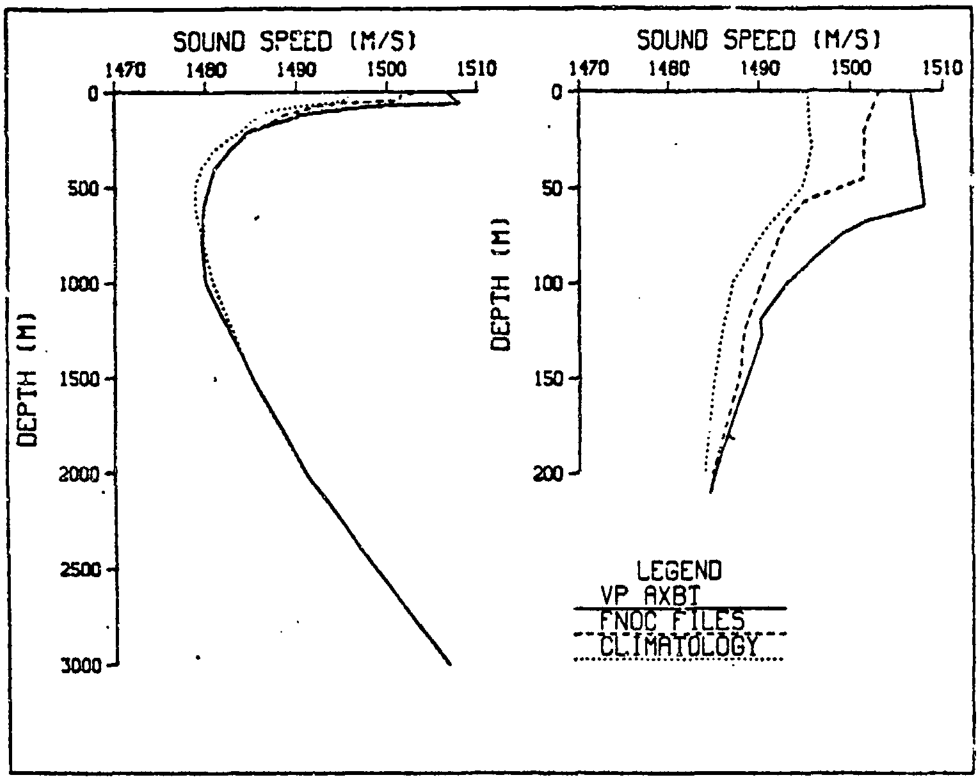

Figure 3.1 Profiles Utilized for SSP Evaluation

IV. RESULTS

A. MEASUREMENTS

On each day of the exercise a different VP aircraft acquired the noise level measurements. Thus, any bias in the error due to the aircraft systems should be present for an entire exercise day. Therefore, a comparison of the prediction errors by date was conducted to indicate possible measurement anomalies.

The statistics computed, shown in figures 4.1 and 4.2, indicate that the measurements acquired on 15 November did not follow the same pattern as on the other dates. The errors associated with the wind related frequencies (440 and 1000 Hz) were extremely high. At these frequencies, DANES predictions were 10 to 13 dB above the measured noise, (see Figure 4.1).

Measured noise levels were expected to be high on 15 November since a storm with 50 kt winds was near the measurement locations. Investigation of the recorded noise levels indicated that the majority of the readings were significantly below that expected. The maximum 1000 Hz noise level acquired on 15 November implied that only 18 kts of wind existed over the receiver. A typical spectrum computed by Donovan (1982) for 15 November is shown in Figure 4.3. The noise levels are one to two standard deviations below the average value computed by Holt (1981) for the NEPAC area. This finding was true for all spectra computed by Donovan from the 15 November flight. As a result, the data for 15 November were considered suspect. The fetch and duration of the storm were considered and no plausable reason other than measurement error could be

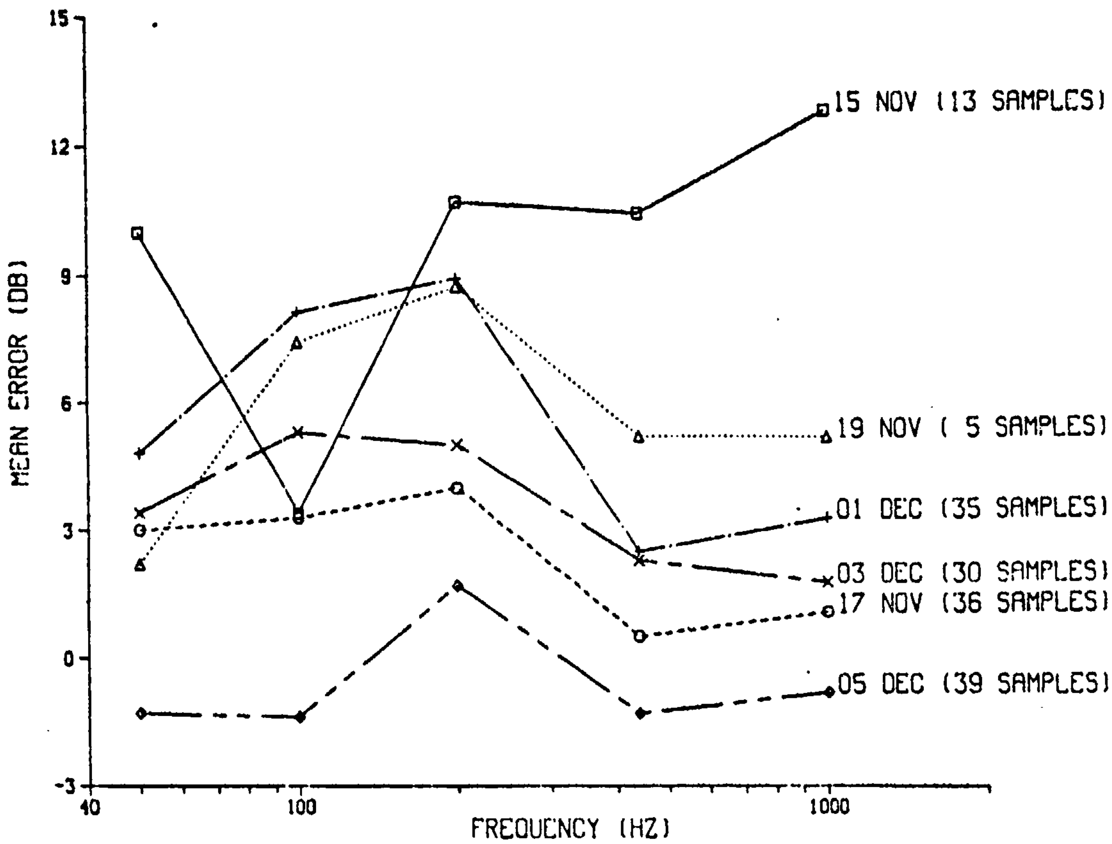

Figure 4.1 Mean Errors Compared by Date of Measurements

established to account for the low noise levels acquired. These measurements, therefore, were not utilized for further analysis.

The negative mean errors on 5 December (see Figure 4.1) were also not characteristic of the other five days. However, the aircrew ambient noise logs on that day indicated nearby shipping on five of the eight sonobuoys. This shipping could account for the measured noise levels being higher than predicted. Additionally, the shape of the curve for the mean error (see Figure 4.1) and the RMS errors (see Figure 4.2) were similar to those for the other dates. Therefore, these data were considered to be representative of the experimental conditions.

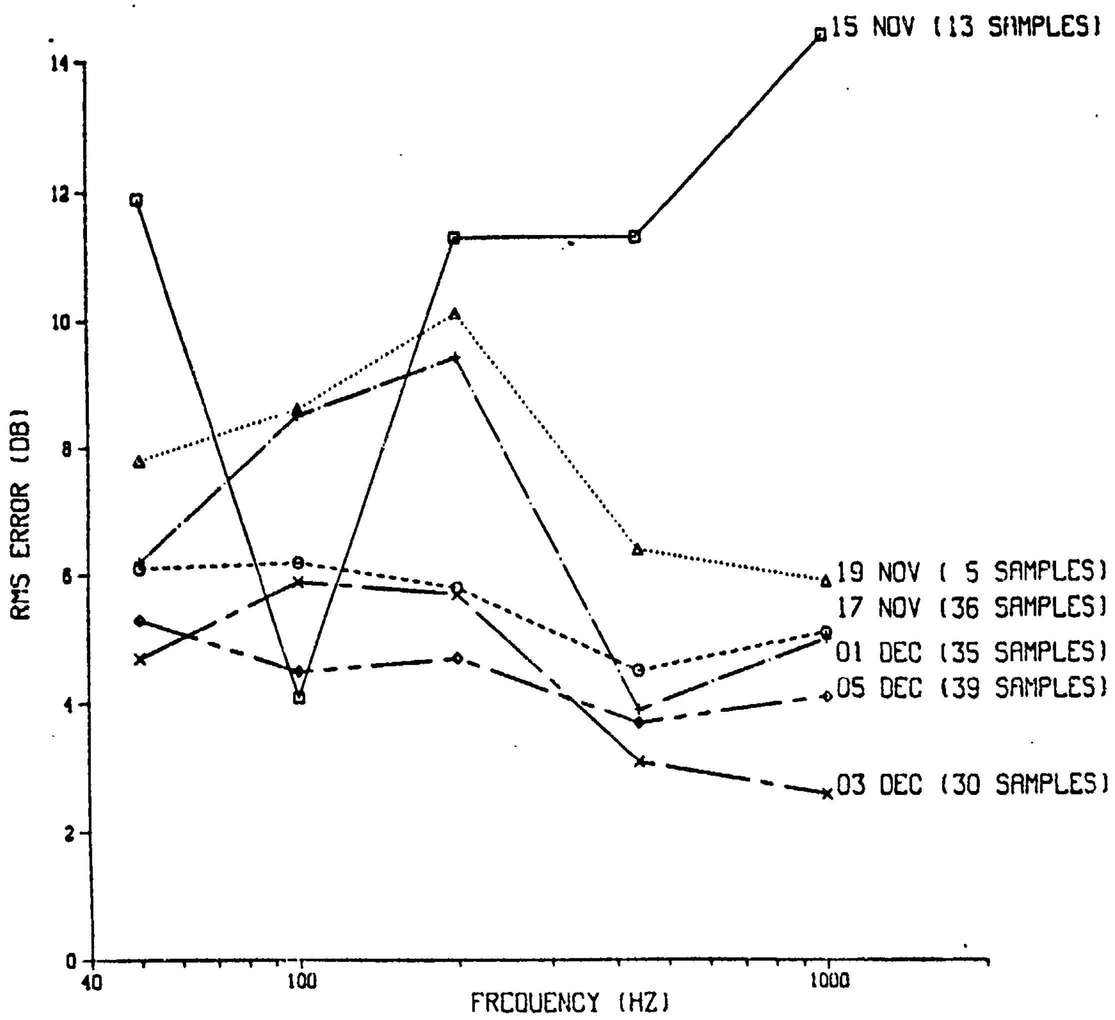

Figure 4.2 RMS Errors Compared by Date of Measurement

The offset between error curves shown in the figures also could be a result of bias introduced by the aircraft. However, other conditions could influence DANES error which would produce similar results. Particularly, HITS shipping densities are monthly representations and do not reflect daily variations.

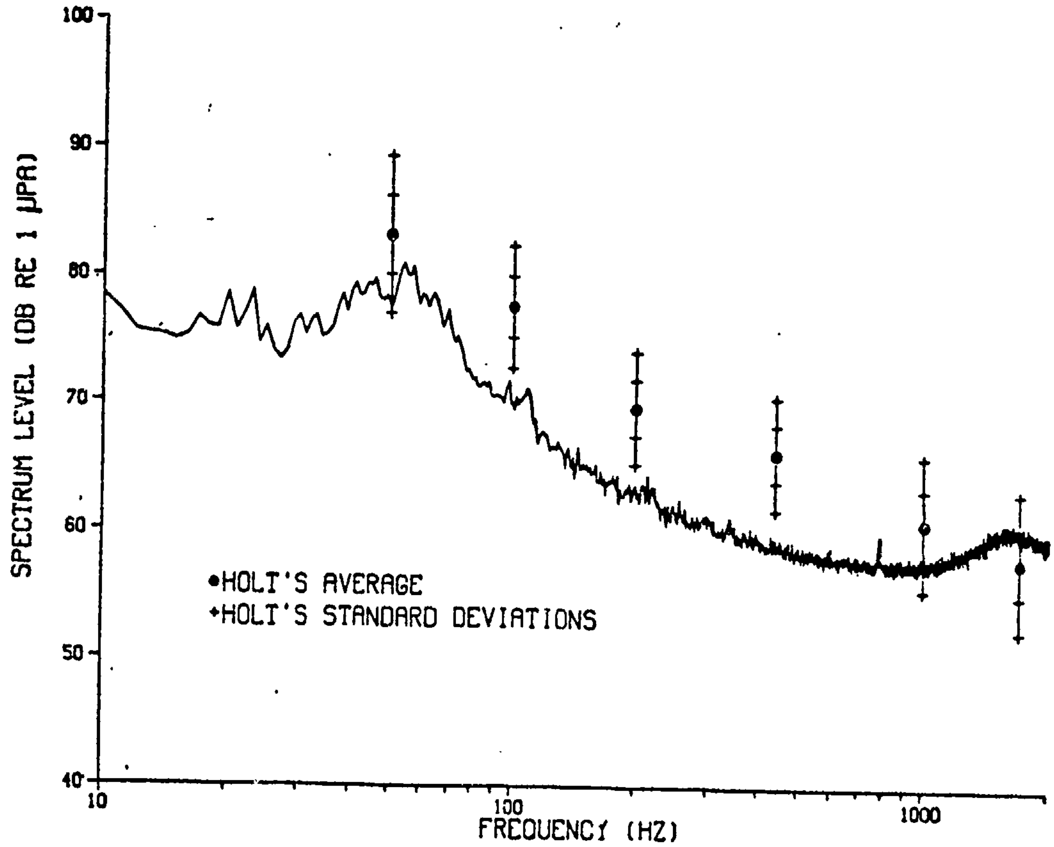

Figure 4.3 Noise Level Spectra (After Donovan, 1982)

B. OPERATIONAL PARAMETERS

The frequency of interest, search depth and search location are parameters of the DANES prediction which are tactically dictated. To a tactician, any relationship between prediction accuracy and these parameters is of concern. Therefore, an analysis of the errors associated with these tactical parameters was conducted.

1. Frequency

The error statistics by frequency for the data set (less 15 November) are shown in Table IV . There was evident a distinguishable error pattern with a maximum error at 200 Hz. The positive mean errors indicated that DANES

TABLE IV

Error Statistics by Frequency

Freq	Mean	Median	Std Dev	RMS
50	2.3	2.5	5.2	5.7
100	3.7	3.9	5.3	6.5
200	4.9	5.3	4.7	6.8
440	1.1	1.1	3.8	4.0
1000	1.4	1.3	4.2	4.4

tended to overestimate the noise levels at all frequencies. The high standard deviations and RMS errors reflected the extreme variation in observed noise levels, while DANES estimations were more consistent. This variability was highest at the shipping frequencies (50 and 100 Hz) as expected. The lowest RMS error, reflective of both mean error and variation, were in the wind frequency regime (440 and 1000 Hz), but these lowest values were only 1 to 2 dB below RMS error values at the other frequencies.

2. Depth

As shown in Figures 4.4 and 4.5 , the selection of receiver depth had little effect on DANES prediction accuracy. The peak error at 200 Hz and characteristic shape of the error curves remained consistent for each depth.

3. Location

The mean error statistics for geographical location (see Figure 4.6) had the same general spectral shape as that of the time (Figure 4.1) and depth (Figure 4.4) parameters. The maximum error at 200 Hz and minimum errors at 440 and 1000 Hz were evident for each latitude band.

Recall from chapter three that the RMS error is equal to the square root of the sum of the mean error squared plus the variation of the error. Therefore, the difference in the spectral shape of the southern location in

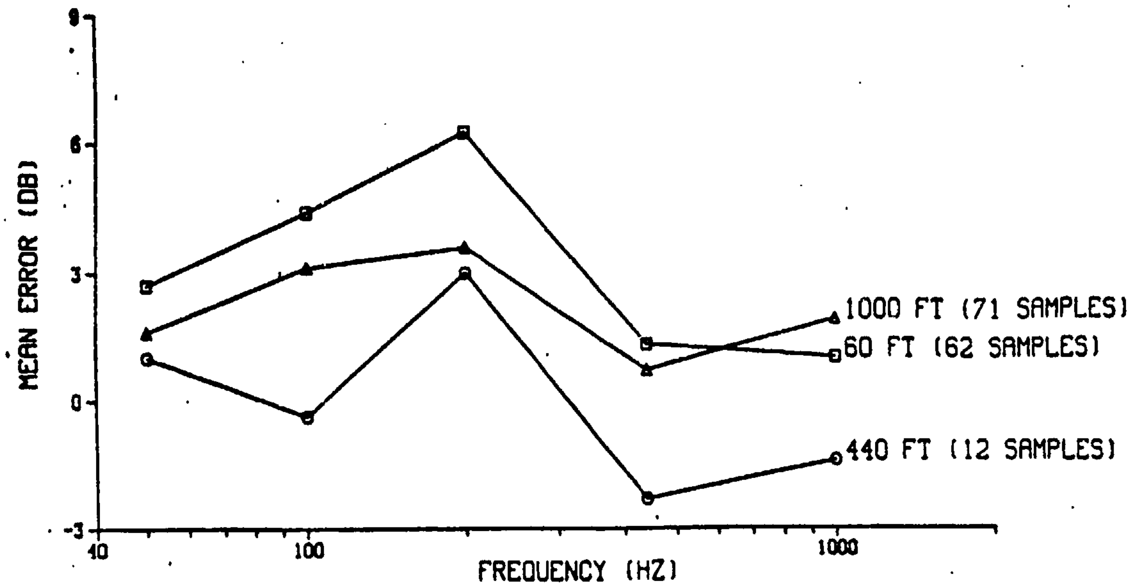

Figure 4.4 Mean Errors Compared by Measurement Depth

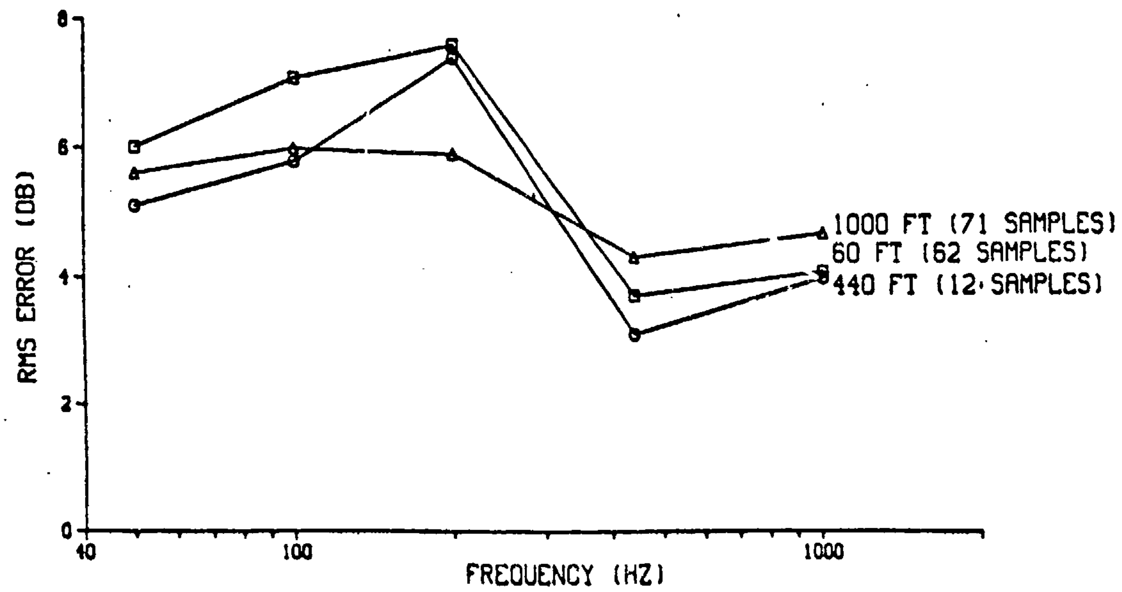

Figure 4.5 RMS Errors Compared by Measurement Depth

Figure 4.7 from that of Figure 4.6 is a due to the variation of the error. The major shipping lanes during the fall and winter (Holt, 1981) are located near the 40.0 to 42.5N lati-

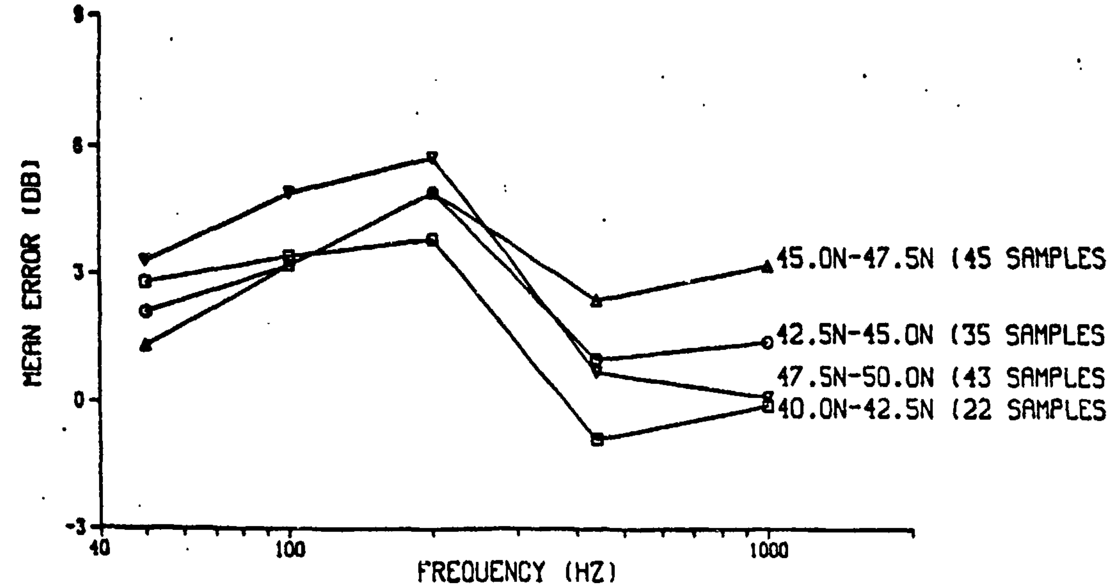

Figure 4.6 Mean Errors Compared by Measurement Location

tude band. Thus, this band shows the high variation for 50 and 100 Hz expected in areas of high shipping concentrations. Likewise, the southern location was dominated by an atmospheric high pressure system with wind conditions that produced little variation in the 1000 Hz noise levels. The storms passing through the northern latitude bands probably produced extremely varying wind conditions which were reflected in the higher frequency noise level measurements.

C. NOISE SOURCES

The accuracy of predicted ambient noise levels is dependent on the accuracy by which the noise sources are modeled. There are four noise sources (two from shipping; two from wind) in the DANES model which can be utilized in various combinations. Statistical evaluation of the prediction errors was conducted according to the individual sources, to identify the contribution each source made to the total error.

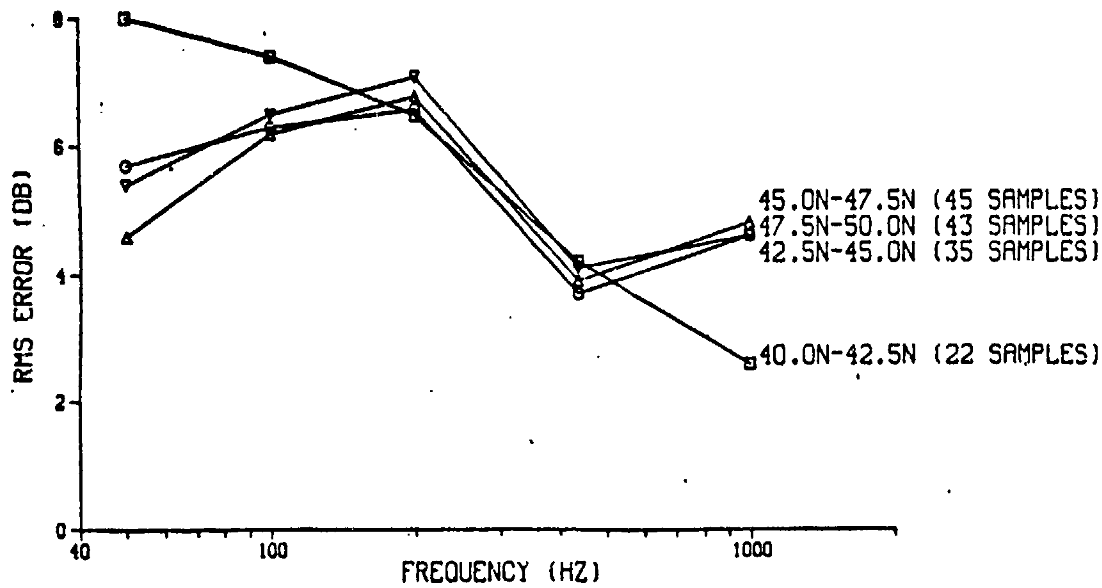

Figure 4.7 RMS Errors Compared by Measurement Location

1. Shipping

The two shipping sources in DANES are historically distributed distant ships (HITS) and discrete synoptic ships (WMO). To investigate the errors associated with WMO shipping only, the HITS data base had to be removed artificially from the DANES noise accumulation. As discussed in the Treatment of the Data, the procedure increased the WMO shipping noise by 3 dB across the spectra for each ship in the DANES transmission loss field of view. This change in spectra should be considered when evaluating WMO statistics.

a. HITS

The previous results, which have been based on comparisons between DANES HITS plus field wind predictions and corresponding measurements, suggest that the HITS contribution overestimates the noise levels in the Northeast Pacific. The mean error at 50 Hz averaged 2.3 dB, (see Table IV). Although not an alarmingly high error, the standard deviation at 50 Hz is considerable, 5.2 dB, presumably due to the fluctuation of the shipping noise. DANES predictions, based on HITS shipping, do not model the fluctuations of a continuously changing shipping field. As shown in Table V, DANES predictions at 50 Hz varied from

TABLE V

Comparison of 50 Hz Noise Level Values

	Mean	Std Dev	Low	High
HITS	86.7	1.9	81.3	89.9
WMO	76.1	5.1	63.2	86.2
Measured	84.6	5.0	72.0	101.0

81.3 to 89.9 dB over the ASTREX period while the measurements acquired (excluding 15 November) ranged from 72.0 to 101.0 dB.

b. WMO

The accuracy of the DANES WMO shipping noise was found to be a function of the ships contained in the transmission loss field of view (see Figure 4.8). This ship count can be related directly to the number of ships that report under the WMO system. For the six days of the exercise, WMO ship counts varied from 28 on 1 December to 447 on 17 November.

Comparison of WMO shipping noise predictions to HITS predictions revealed that the WMO prediction was always much lower than the Hits prediction. In Figures 4.9 and 4.10 , the comparisons are shown between the error statistics associated with four combinations of DANES inputs: (1) HITS shipping with local winds, (2) HITS shipping with field winds (3) WMO shipping with local winds, and (4) WMO shipping with field winds. As indicated in figure 4.9 , extreme negative errors existed at 50 and 100 Hz when WMO shipping

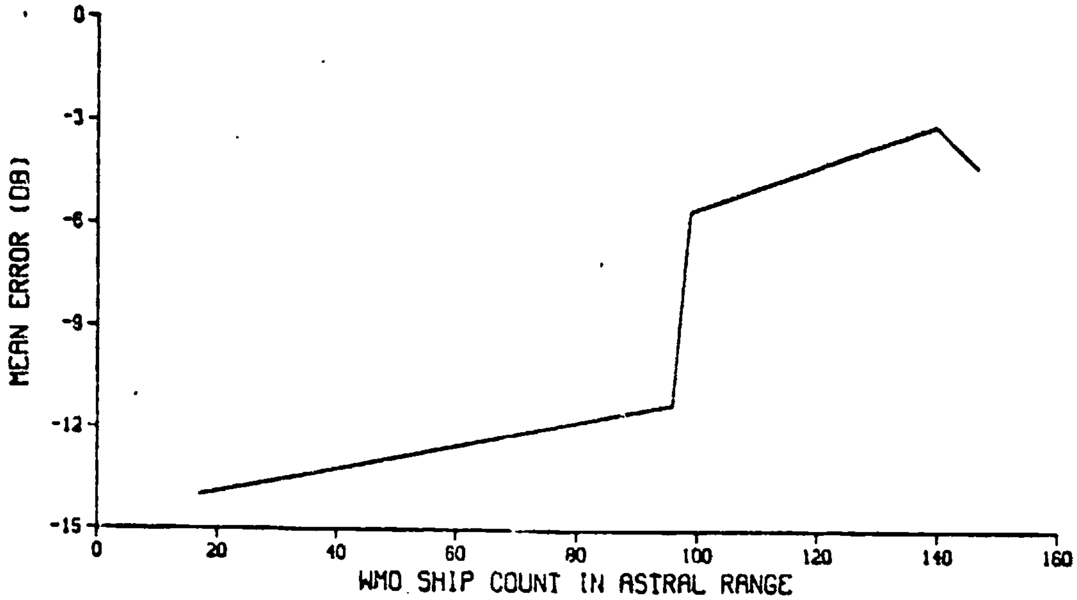

Figure 4.8 Mean 50 Hz Error by WMO Ships Utilized

was utilized. This result suggests that the WMO shipping reports do not accurately portray the actual shipping in the Northeast Pacific. However, the utilization of these lower shipping noise contibutions resulted in an interesting observation at 200 Hz. Shown in Figures 4.9 and 4.10 , when WMO shipping was utilized the high mean and RMS errors associated with HITS shipping inputs were reduced and were more in agreement with the higher frequency errors.

2. Wind

The wind sources of the DANES model can be specified as local wind only or local wind plus distant wind effects. As in shipping, the accuracy of the wind input affects the accuracy of the wind noise estimation. At present, the NOGAPS model at FNCC provides the wind speed input for predictions based on synoptic winds. In 1980, however, the Primitive Equation (PE) model was the atmospheric model utilized. It was the PE model wind fields extracted from archived data files at FNOC that were utilized in this study.

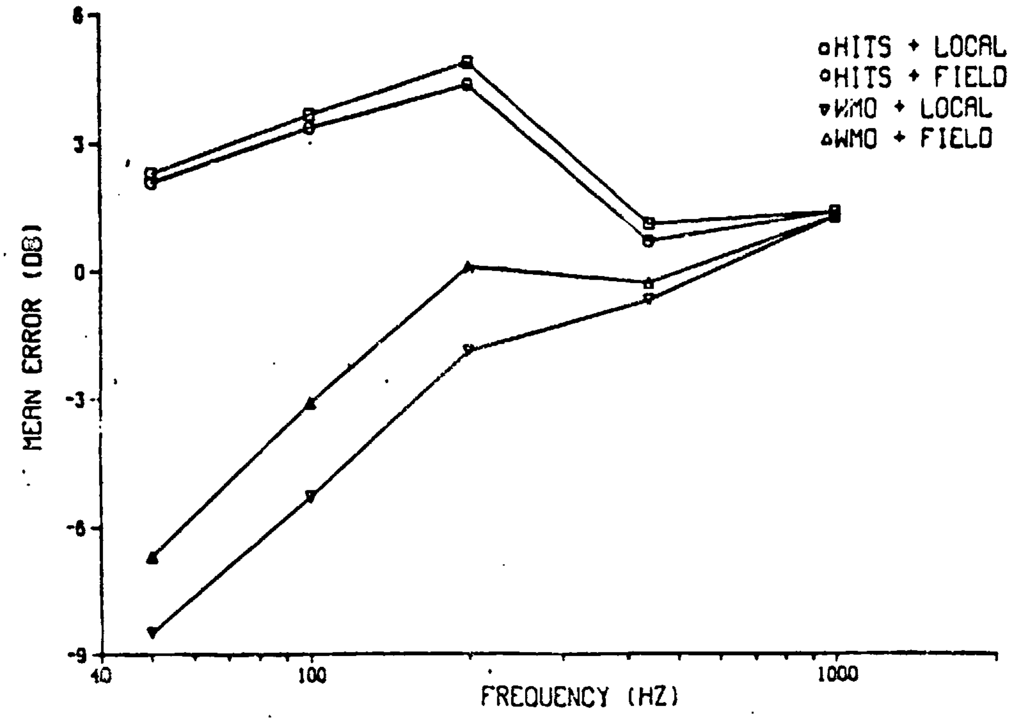

Figure 4.9 Mean Errors Compared by Input Noise Sources

a. Local Wind

As shown in Figure 4.9, at 440 Hz and above there is little difference between the mean errors associated with predictions utilizing field winds compared to predictions utilizing local winds. One can assume therefore, local wind is the dominant source in the model above 440 Hz.

The mean errors and RMS errors shown in Figures 4.11 and 4.12, respectively, are presented as a frequency distribution grouped by PE forecasted local wind speeds. In Figure 4.11, the positive mean errors at 440 and 1000 Hz for wind speeds above 1 kts indicate that PE overestimated the local wind. However, at 10 to 15 kts the opposite is true.

In Figure 4.12 the RMS error at 1000 Hz illustrates the variation of the error. In figure 4.11 the 10 to

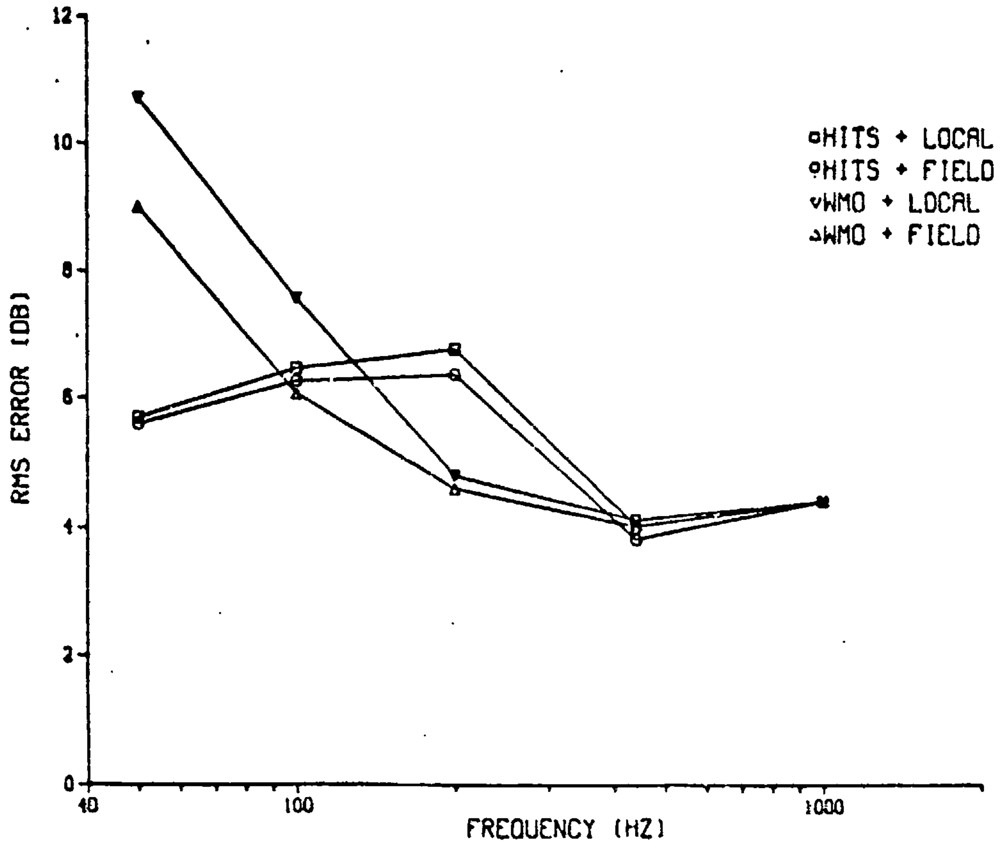

Figure 4.10 RMS Errors Compared by Input Noise Sources

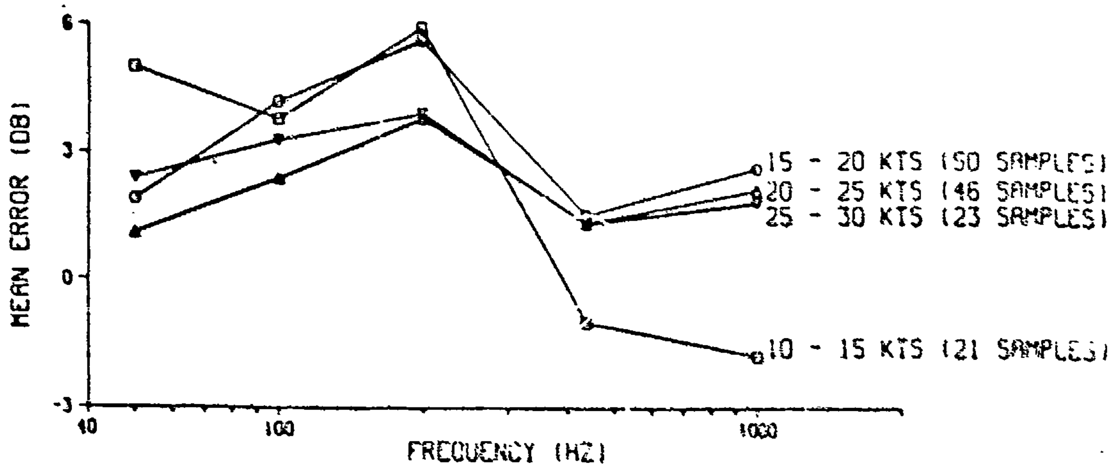

Figure 4.11 Mean Errors Compared by Forecasted Local Wind

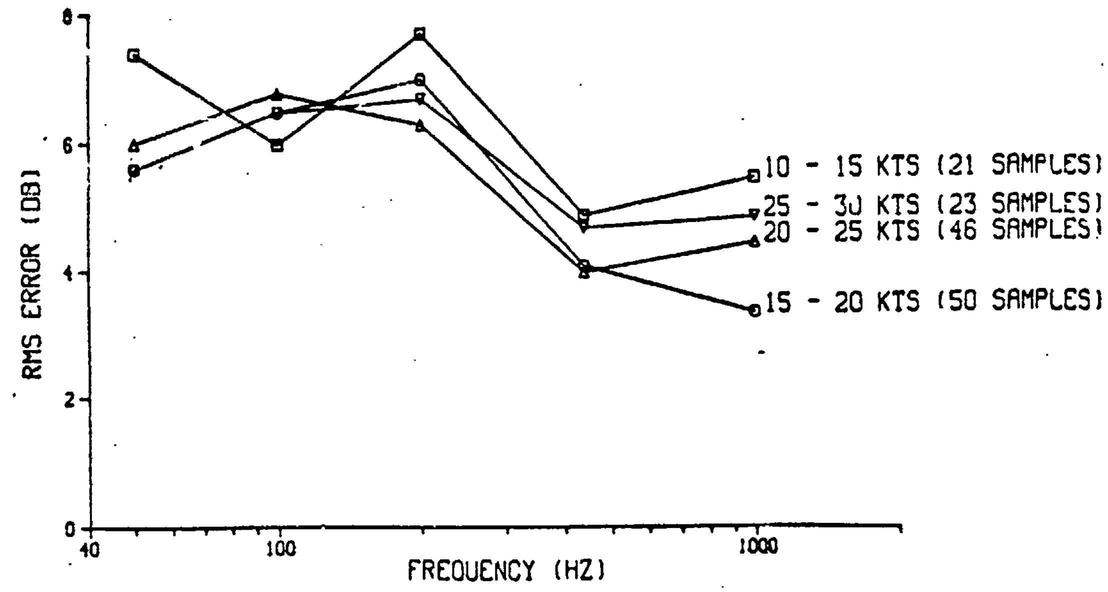

Figure 4.12 RMS Errors Compared by Forecasted Local Wind

15 kt local wind forecasts had the lowest absolute mean error (-1.7 dB); however, the same wind speed regime had the highest variation in error as shown in Figure 4.12 . The opposite is true for the 15 to 20 kt wind regime.

b. Distant Wind

As noted earlier, the noise prediction error above 440 Hz was a function of the accuracy of the local wind input only. Field wind inputs to the model had little effect on the errors at these higher frequencies. Further, Figures 4.9 and 4.10 indicate that when the HITS data base is utilized for modeling shipping noise, there is only a minor difference in errors between local and field wind inputs for frequencies below 440 HZ. However, examination of the mean and RMS error curves when the WNO shipping input was utilized indicates that the wind field input contributed an average of 2 to 3 dB to the noise levels below 200 Hz. According to the model, therefore, if the observed shipping noise level is below that estimated by HITS, distant storm effects should be present at frequencies below 200 Hz.

To investigate low shipping conditions, data where nearby shipping was present in the measurements were removed. No significant new findings were indicated by this analysis.

D. OCEAN MEDIUM

Three sound speed profiles (SSP) were utilized to determine DANES sensitivity to the oceanic vertical structure. The profiles consisted of: (1) the DANES climatological profile, (2) an FNOC profile based on synoptic and climatologically blended temperature profiles, and (3) a profile based on synoptic AXBT information. Each SSP was inserted in the DANES model as the initial oceanic profile. DANES climatological profiles were utilized beyond the first oceanic change. The resulting ASTRAL transmission loss

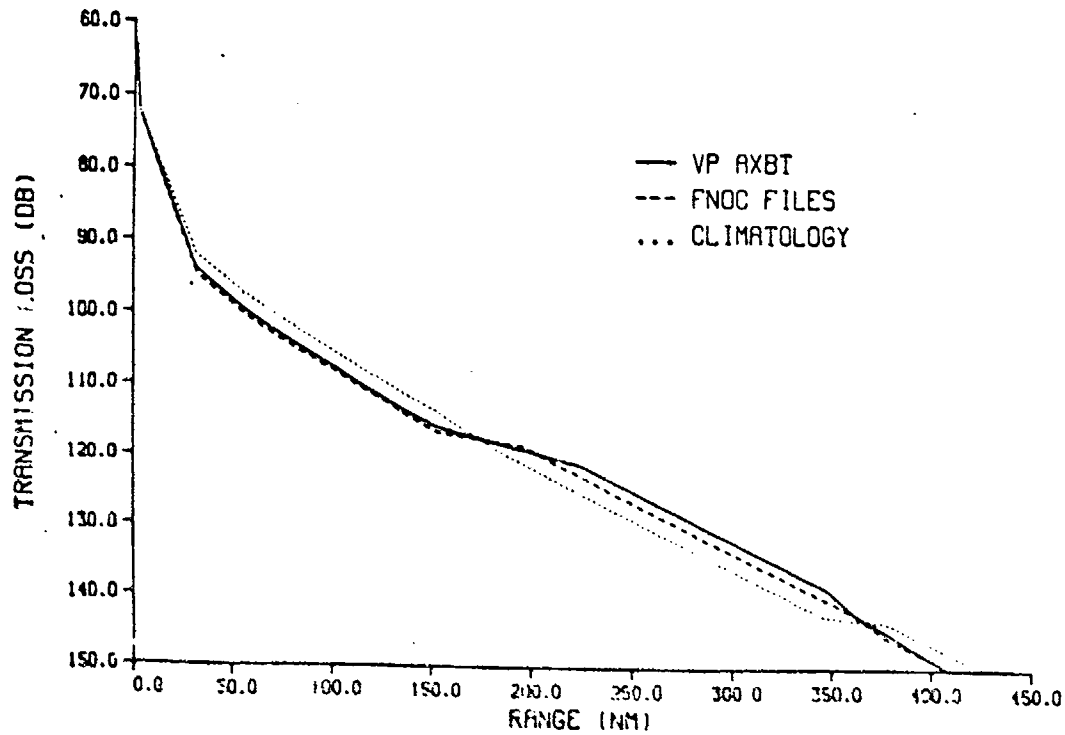

Figure 4.13 Transmission Loss Comparison by SSP Input

curves are shown in figure 4.13 Due to ASTRAL's technique of utilizing the initial SSP to a range of 150nm and then continuing with climatological SSP files, very little difference in transmission loss is obtained. The differences in ambient noise estimations as a result of the different initial SSPs are given in Table VI . There is relatively no difference between predictions made with

TABLE VI

DANES Predictions Compared by Initial SSP Input

Freq	Climatology	FNOC	AXBT
50	88.3	87.6	87.4
100	82.3	81.0	81.0
200	75.3	73.7	73.6
440	67.6	67.0	66.8
1000	63.8	64.0	63.7

FNOC'S SSP and those which were computed utilizing synoptic AXBT information. Only small differences are apparent when compared to a prediction made with climatological profiles. The largest difference (1.7 dB) occurred between the climatological profile and the AXBT profile at 200 Hz.

V. DISCUSSION OF RESULTS

A. MEASUREMENTS

Measurement errors due to uncalibrated sonobuoys were considered. These errors of a random nature were assumed to cancel as a result of a large sample size. Aircraft equipment errors, however, were capable of introducing a bias to the measurement. Separation of the data by individual flight revealed that the ambient noise measurements acquired by the VP aircraft on the first day of the exercise were excessively low. These measurements were considered to be erroneous and, therefore, were not utilized in the analysis.

B. OPERATIONAL REQUIREMENTS

DANES prediction errors associated with operationally dictated parameters were investigated. The parameters considered were frequency of interest, receiver depth, and search location.

1. Frequency

An apparent frequency related error occurred at 200 Hz. This large error was predominant at all depths and measurement locations. A similar result was evident in COMTHIRDFLT's (1982) study which compared the accuracy of DANES predictions to other prediction methods. In that study, the 200 Hz error was 3 to 4 dB higher than the 100 Hz error for both ocean regions investigated. Additionally, as shown in Figure 5.1 , a second study performed by COMTHIRDFLT (1982) indicated the same 200 Hz error peak for a 60 ft hydrophone. This large error appears to be a function of the shipping noise model, which will be discussed

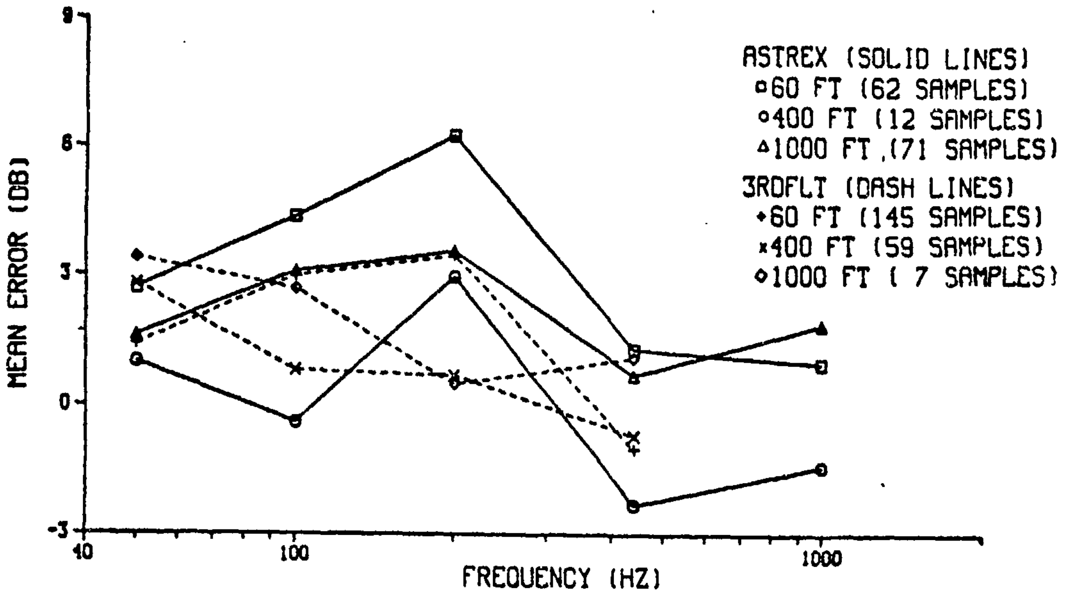

Figure 5.1 Mean Errors Compared with COMTHIRDFLT's (1982)

later. The lowest mean and RMS errors were found to be at 440 Hz which agrees with the results presented in COMTHIRDFLT second study. COMTHIRDFLT's study did not include the 1000 Hz error value, which here is comparable to the 440 Hz error. These low values suggest that the local wind noise is the most accurate prediction. Both studies indicate that DANES markedly overestimates the noise level below 200 Hz. At 440 Hz the studies differ and will be discussed later.

2. Depth

A depth dependence of the DANES error could not be shown. The RMS error was lower at the 400 ft depth for all frequencies except for 200 Hz; however, the maximum difference between the error at any depth and frequency was only 1.7 dB. The lowest RMS error occurred at 400 ft for 440 Hz which agrees with COMTHIRDFLT (1982) findings (see Figure 5.2). COMTHIRDFLT indicated that DANES error was highly

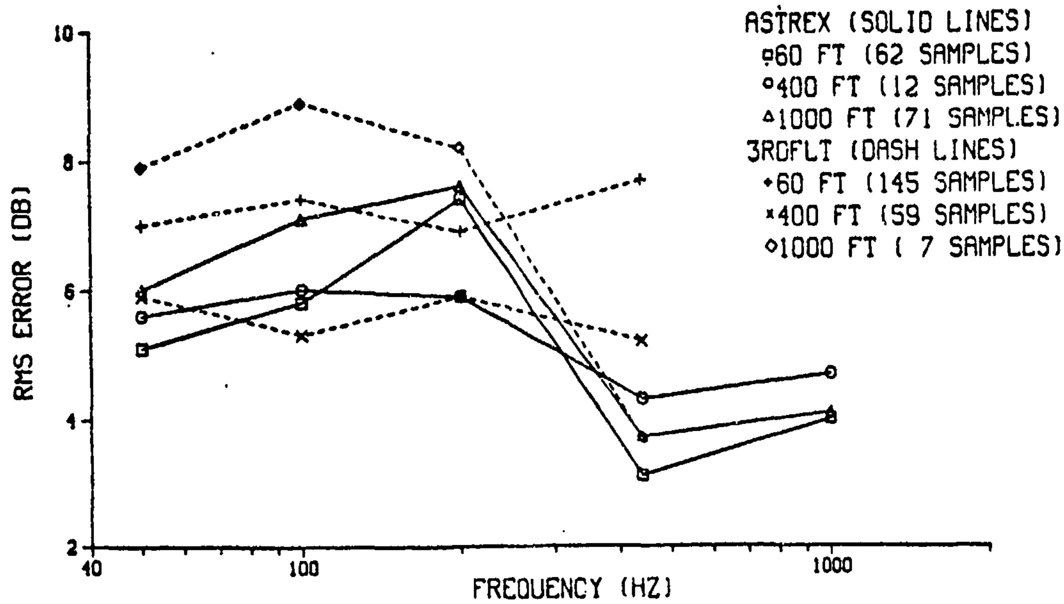

Figure 5.2 RMS Errors Compared with COMTHIRDFLT's (1982)

depth dependent; however, that result was shown by higher order statistics which were not performed in this study.

3. Location

DANES prediction accuracy shows no dependency on any particular location in the NEPAC area based on the mean error values. The RMS error, however, indicates the prediction error may be affected by variability of the noise source in the vicinity of shipping lanes and storm tracks.

C. NOISE SOURCES

DANES models two sources of ambient noise: shipping and wind. Two inputs are available for each of these sources. An evaluation of each input noise source was performed to determine the error associated with each particular input.

1. Shipping

The two DANES shipping inputs are historical shipping densities (HITS) and discrete synoptic shipping (WMO).

a. HITS

A comparison is made in Figure 5.3 between various DANES estimations and data acquired at one measurement site on 17 November. The dominance of the HITS data base below 300 Hz is apparent from the following comparison of the predicted spectra. The difference between all shipping plus wind and WMO shipping plus wind curves is the addition of the HITS data base. As shown, this additional source increased the noise level by 5 to 10 dB at the lower frequencies. Due to the logarithmic nature of noise accumulation, the differences often reflect the contribution of the dominant noise source only. Not shown, but computed, were noise levels with the HITS shipping contribution only. These levels were less than 1 dB lower than those shown with both shipping sources.

The results shown in Figure 5.3 indicate that the DANES prediction, which utilized all available model sources, estimated the actual ambient noise levels well. Since HITS, which was shown to be the dominant source below 300 Hz, is not intended to be indicative of nearby shipping, these results are of interest. The ambient noise records indicated that a ship was in the area of the measurement site. The tonals present below 100 Hz in Donovan's spectrum is evidence of that ship. Although this particular case indicated overall close agreement, use of the HITS data base provided ambient noise estimations that averaged 2 to 5 dB higher than values measured in the frequency range of 50 to 200 Hz; the highest error occurred at 200 Hz. These results suggest that the HITS noise level estimations for the

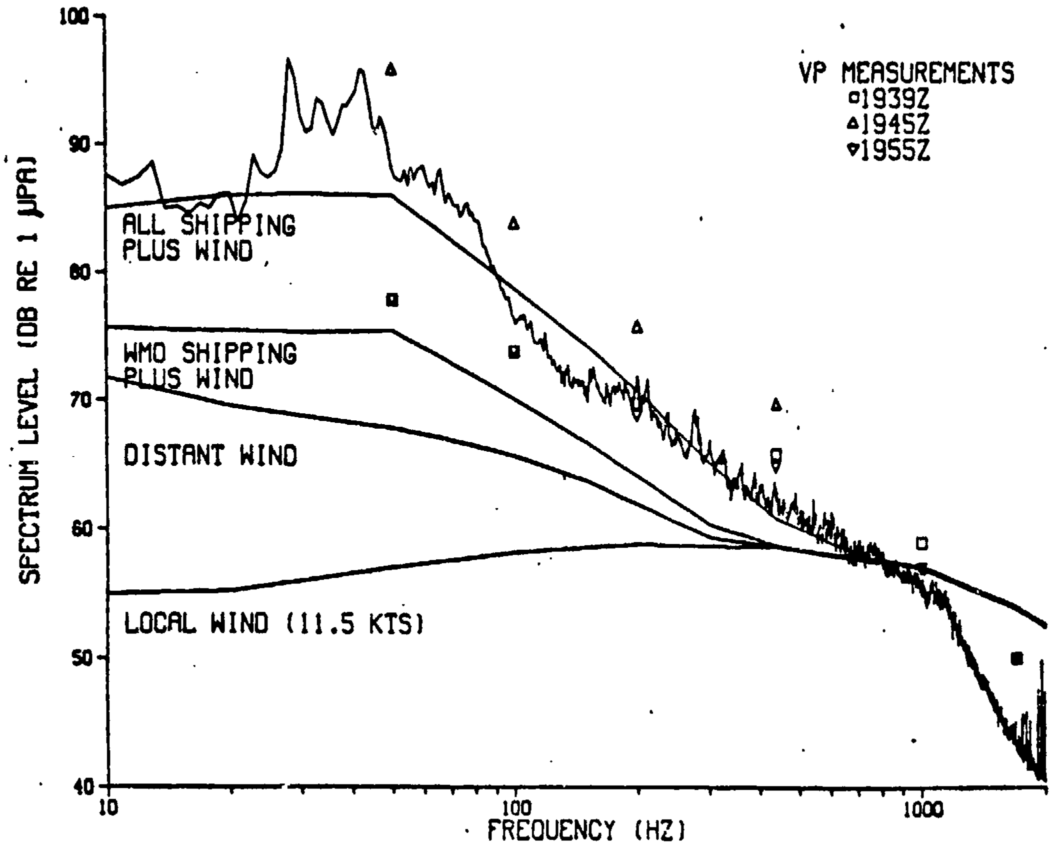

Figure 5.3 DANES Compared with Measurements of 17 NOV

Northeast Pacific represent noise of nearby shipping rather than distant shipping.

b. WMO

As shown in Figure 5.3, WMO shipping alone is often not representative of the shipping noise field. The estimations obtained for 17 November from WMO were the highest as a result of 447 ships reporting under the WMO system. However, the ship count and the resulting contribution from WMO shipping are highly variable. To determine the impact WMO shipping contributions have on the noise estimation, predictions for 17 November were made from 1800z through 2400z at 15 minute intervals. No significant changes in noise levels were indicated over this time period. This result indicates that either WMO shipping is not significant enough or it is not accurate enough to indicate expected increases in the ambient noise level. This result also concurs with the findings of Malay (1982). Malay indicated that background shipping noise levels at a particular location varied little over a 24 hr period. However, individual shipping traffic produced extreme noise levels that were not indicated by the DANES average noise level prediction.

2. Wind

The two DANES wind inputs are either local wind only or local wind plus field wind effects.

a. Local Wind

The local wind is the dominant component in the DANES model above 400 Hz. For ambient noise estimations made at these frequencies, the accuracy of the prediction is primarily dependent on the accuracy of the local wind speed input. Investigation of the DANES prediction accuracy at 1000 Hz indicated that the wind speed input to DANES from the Primitive Equation model is predominantly overestimated. The present atmospheric model at FNOC which provides wind inputs to DANES is NOGAPS. Since the prediction error at 440 Hz was negative at 60 and 400 ft in COMTHIRDFLT's (1982) study, (see Figure 5.1), indications are that NOGAPS underestimates the wind speed. However, no extensive study has been conducted to verify NOGAPS wind speed accuracy. Cursory studies by Lazanoff and Kaitala (1983) and Raysin (1983) have presented conflicting results which suggest the NOGAPS wind error may be seasonally dependent.

Although the mean error at 440 and 1000 Hz was shown to be low (less than 2 dB), the RMS error reflects a high variance. This high variation in the noise prediction error is believed to be a result of at least two mechanisms. First, investigation of the prediction error by latitude bands indicated the highest variation in the error for 1000 Hz occurred for measurements acquired between 47.5 and 50.0N. This variation is believed to result from the passage of storms which produced variable noise conditions over short periods of time. Additionally, the investigation of the prediction error by wind speed revealed that high variation in the error at this frequency occurred for wind speed predictions between 10 and 15 kts. It is believed that this occurs because a slight error in wind speed produces a larger error in noise estimation at low wind speeds than at higher wind speeds. For example, between 10 and 13 kts the difference in DANES noise level estimation is 4.4 dB, whereas, for 25 and 28 kts the difference is 1.1 dB. This difference implies DANES accuracy is more sensitive to wind speed accuracy for low wind conditions.

b. Distant Wind

The model indicates that distant wind effects can contribute significantly at frequencies less than 200 Hz. However, due to the dominance of the HITS contribution, DANES predictions in this study did not seem to reflect the contribution from a distant storm in the NEPAC area.

These results are illustrated in Figure 5.4, where the modeled noise from various sources is compared to acquired data at one measurement site on 1 December. The local wind estimation appears to agree with the measurements at 1000 Hz. Approximately 600 to 700 nm to the northwest of the measurement site, 30 kt winds were reported. As a result of these distant winds, DANES indicates a 4 to 6 dB increase in the noise level from 10 to 200 Hz. At 200 Hz, the prediction based on wind inputs alone is in close agreement with the measurements. The WMO shipping reports were

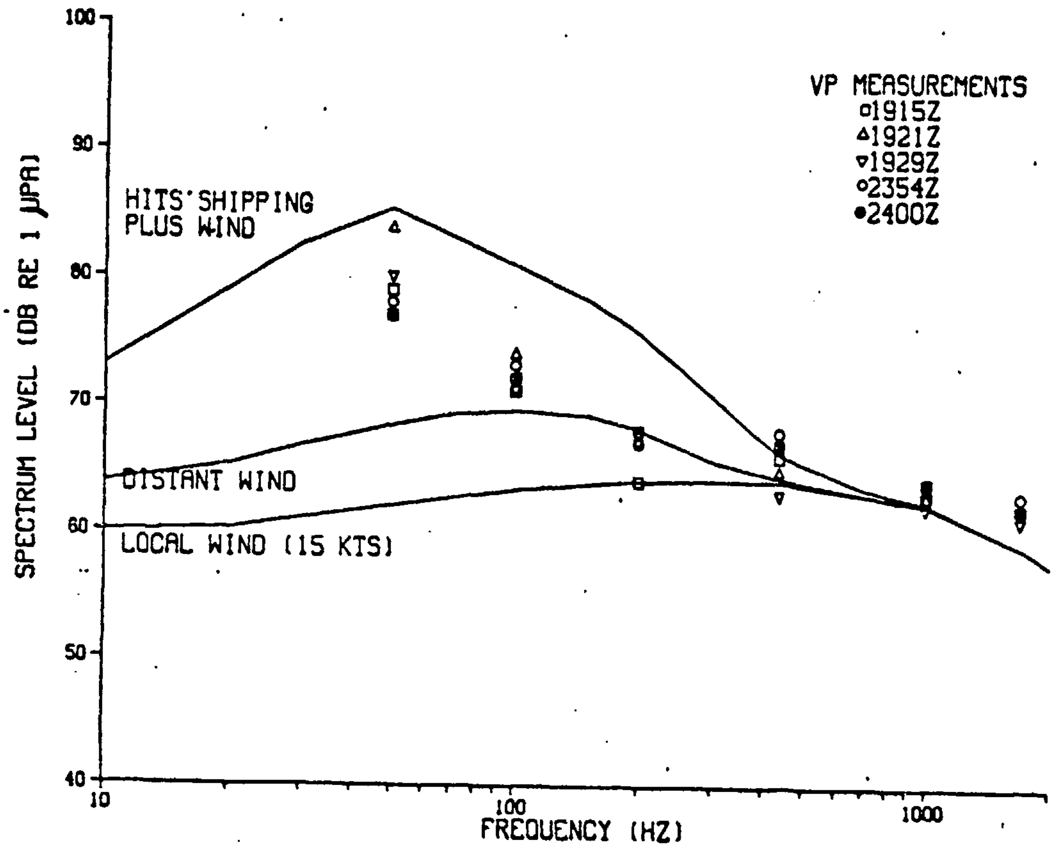

Figure 5.4 DANES Compared with Measurements of 1 DEC

extremely sparse on that date, with only 28 ships reporting for the entire Pacific. Therefore, the contribution from WMO shipping is not shown, as it was less than 1 dB. When the HITS data base is added to the noise prediction, the resultant spectrum exceeds measurement values by an average of 5 dB at 50 to 200 Hz. A comparison was conducted, between the DANES predictions made with HITS shipping and either local winds only or with local winds plus distant winds. No significant difference between the noise level estimations was found.

D. OCEAN MEDIUM

This study indicated that, due to ASTRAL's technique of modeling transmission loss, the initial SSP contributes only minutely to the DANES prediction. However, the impact on the DANES accuracy is still in question. Only large scale ocean features can be modeled, and, thus, the DANES predictions may not be accurate in complex ocean environments (Lukas, 1983).

VI. CONCLUSIONS AND RECOMMENDATIONS

The DANES ambient noise hindcasts of November and December 1980 when compared with measured ambient noise levels indicated a number of weaknesses in the DANES model. In this comparison, the large data base of measured noise levels were assumed accurate. This assumption is reasonable even though some data were omitted due to suspected measurement errors. The following summary of results should be considered valid only for the Northeast Pacific during the winter, and, should not be considered an indication of DANES performance in other ocean regions or seasons.

A. EVALUATION OF DANES PERFORMANCE

Overall, DANES overestimated the noise levels in the Northeast Pacific. These errors averaged from 1 to 5 dB, depending on frequency. However, the perceived accuracy of DANES could be influenced by two factors. First, the measurements for which DANES predictions were compared were possibly in error. Secondly, DANES provided an average expected noise level of a highly variable phenomenon.

1. Measurement Errors

ASTREX 1980 was conducted with operational assets which were considered to be generally within manufacturer's specifications. Calibrations were not conducted and some measurement errors were probably introduced. However, these errors could be considered random and should cancel with a large sample size. Comparison of DANES predictions with only a few measurements would not have demonstrated DANES accuracy. For example, had DANES been compared only with the measurements of 15 November, the prediction error would have been excessive. The findings of this study indicate the aircraft equipment for 15 November may not have been within specified tolerance.

Conclusion

Utilization of uncalibrated measurements for model evaluation provides some uncertainty as to the results obtained. However, the large sample size and critical analysis of the data provided a reasonable evaluation of the model's performance.

Recommendations

Similar studies should be conducted again to study DANES performance and ambient noise characteristics. Such an experiment, "Ocean Storms", has been scheduled to be conducted in the Northeast Pacific (50N, 135W) in the fall of 1986. The Environmental Acoustic Research Group at NPS plans to participate in this multi-institutional air/sea experiment. Ocean Storms should provide an excellent opportunity for another ambient noise model verification experiment.

Calibrated equipment should be utilized during Ocean Storms for the model verification to limit the possible occurrence of measurement error. Fewer measurement sites with more measurements acquired at each location would be beneficial. By limiting the number of sites and increasing the sampling rate, a better understanding of the oceanic effects on the model should be obtained. The Ocean Storms experiment will be located near a moored NDBC buoy. Such buoy data should provide an accurate local wind speed measurement for comparison to model predictions. However, nearby shipping effects may hinder analysis of the ambient noise sources at that location.

2. Noise Variability

Ambient noise in the ocean is highly variable. DANES attempts to provide some representation of this variability by utilizing discrete (WMO) shipping reports and a time step capability. However, the final output of the model is an average noise level for a given time period. This average level is reported as a single value given to one tenth of a decibel. No variability is indicated. In this thesis, the standard deviation of the error in the DANES prediction was 4 to 5 dB. If DANES provided a perfect average prediction, the standard deviation indicates that the actual noise could be within these limits only 67 percent of the time. This variability in the noise field is significant to an operator who is attempting to apply the DANES prediction tactically.

Conclusion

Short term variability of ambient noise is not properly modeled by DANES, nor is it indicated in the prediction.

Recommendation

Until the DANES model is sophisticated enough to provide changes in ambient noise levels due to such variables as nearby shipping or convergence zone effects, an expected noise distribution should be provided along with the average expected value. This variability could be empirically derived in a number of ways. For example, ambient noise studies which provide the climatological average and variability of ambient noise could be used. Results of DANES prediction accuracy, such as presented in this thesis, could also be useful.

B. SOURCES OF DANES ERROR

The parameters considered which possibly could be related to the DANES error included operationally dictated parameters, noise source model inputs and oceanic model inputs. The following parameters appeared to contribute to the DANES prediction error.

1. HITS shipping

The HITS data base for the Northeast Pacific provided noise level estimations that represented measurements acquired when nearby shipping was known to be present. Under distant shipping conditions, predictions made utilizing HITS overestimated the noise level by an average of 2 to 3 dB at 50 and 100 Hz. The noise contribution from HITS dominated the noise spectrum below 300 Hz, overriding any contribution from WMO shipping or distant winds. These excessive levels appear to be a result of shipping density errors instead of shipping spectra errors, since different results are obtained in ocean regions other than the Northeast Pacific. However, a possible spectrum related error appears at 200 Hz. At this frequency a maximum mean error occurred when the HITS data base was utilized. This error diminished and appeared more wind related with a quieter shipping noise source. Two studies by COMTHIRDFLT (1983) also support this finding of a maximum error at 200 Hz.

Conclusion

The HITS data base overestimates the shipping generated ambient noise below 300 Hz by an average of 2 to 3 dB.

Recommendation

The HITS data base in the Northeast Pacific needs to be reevaluated. Current shipping densities and preferred ship routing patterns should be acquired from ship routing services. The shipping spectra should be evaluated further to determine if the high error at 200 Hz indicated by this thesis could be related to the shape of the HITS shipping spectra.

2. WMO shipping

The number of ships reporting under the World Meteorological Organization (WMO) system each day was found to be highly variable. In the Pacific, ship counts varied from 28 to 447 during ASTREX. This variability significantly influenced DANES' ability to utilize the WMO shipping in ambient noise predictions. Normally extremely low, WMO shipping did not contribute sufficiently to the ambient noise below 200 Hz in the prediction. When the HITS data base was utilized, the WMO ships were overridden by the high HITS noise levels. As a result, DANES predictions made with historical (HITS) plus synoptic (WMO) shipping were no different than if the prediction had been made with historical shipping only. Therefore the utilization of synoptic shipping did not improve short term ambient noise predictions.

Conclusion

The reliance on the WMO for individual shipping locations did not provide sufficient information for ambient noise estimations based on WMO shipping information alone. When coupled with HITS, WMO shipping is normally overridden by the high noise levels computed from the HITS data base. If WMO shipping did contribute, it could only increase an already high estimation. As a result, there was no enhancement of the prediction accuracy from that of a prediction based on historical (HITS) data alone.

Recommendation

To provide a reasonable short term ambient noise prediction to a carrier task force, it is recommended that the DANES model be modularized for compatability with smaller shipboard computers. Magnetic disk files could be loaded selectively to reflect the oceanic conditions of the operating area and historical shipping. Instead of WMO shipping information, the surface shipping plot could be entered directly from the Tactical Datalink System (TDS). This shipping input should be accurate to a given range, allowing the HITS data base to be blanked out to that range. HITS contributions would be thereby reduced and discrete shipping contributions increased. A local wind input would be relatively easy to insert. Other means would need to be developed to input a wind field.

3. Transmission Loss

The ASTRAL model provides DANES with a fast means of computing transmission loss along a radial. Assumptions in the ASTRAL model may have rendered the model insensitive to environmental changes. The utilization of a single SSP within the first 150 nm of the receiver location and averaging through convergence zones precludes modeling of small scale ocean features. As a result, ambient noise predictions made utilizing synoptic SSP indicate little or no difference compared to predictions with climatological profiles only.

Conclusion

The DANES transmission loss model is insensitive to the sound speed profile. ASTRAL's range smoothing and homogeneous ocean assumption within 150 nm of the receiver precludes any major contribution from synoptic as compared to climatological profiles.

Recommendation

The DANES model should be evaluated utilizing both the ASTRAL model and another transmission loss model such as th PE model. This evaluation would be limited, however, due to the longer computer processing time required by these other models. To reduce the computer requirements, a new transmission model may be necessary.

C. EFFECTS OF LOCAL VERSUS DISTANT WIND

According to DANES, distant storms were not significant to the noise level spectra in the Northeast Pacific. Due to sound attenuation of the higher frequencies in the model, local winds dominated the noise spectrum above 400 Hz. The high noise levels generated by the HITS data base dominated the spectrum below 300 Hz.

From model results and the work by Wilson (1983), the measurements were investigated for distant storm noise influences between 100 and 300 Hz. At measurement times and locations where distant storm effects were believed to be observable, nearby shipping effects appeared to dominate the spectra. Due to the limited number of cases avilable, no conclusions could be made as to the actual influences of distant storm generated noise.

Conclusion

In the Northeast Pacific, wind generated noise from distant storms was not a significant factor in the DANES predictions. Local wind effects seemed to dominate the noise spectrum above 400 Hz. The shipping noise contribution from the HITS data base dominated the predictions below 300 Hz.

Recommendation

Further study of storm generated noise needs to be performed. As previously stated, an excellent oppcrtunity exists with the Ocean Storms experiment in the fall of 1986.

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Unavailable	Raysin, K. L.	COMPARISON OF OBSERVED AND PREDICTED AMBIENT NOISE IN THE NORTHEAST PACIFIC, WINTER 1980	Naval Postgraduate School	840601	ADB099796	U
Unavailable	Spofford, C. W.	FINAL REPORT ON CONTRACT N00014-83-C-0303	Science Applications International Corporation	850401	ADA155559	U

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Ser 321OA/011/06
31 Jan 06

MEMORANDUM FOR DISTRIBUTION LIST

Subj: DECLASSIFICATION OF LONG RANGE ACOUSTIC PROPAGATION PROJECT (LRAPP) DOCUMENTS

Ref: (a) SECNAVINST 5510.36

Encl: (1) List of DECLASSIFIED LRAPP Documents

1. In accordance with reference (a), a declassification review has been conducted on a number of classified LRAPP documents.

2. The LRAPP documents listed in enclosure (1) have been downgraded to UNCLASSIFIED and have been approved for public release. These documents should be remarked as follows:

   Classification changed to UNCLASSIFIED by authority of the Chief of Naval Operations (N772) letter N772A/6U875630, 20 January 2006.

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3. Questions may be directed to the undersigned on (703) 696-4619, DSN 426-4619.

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By direction